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WATER RESOURCES: UTILIZATION AND CONSERVATION IN THE ENVIRONMENT

M. C. Blount

Fort Valley State College

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This report consists of twenty-three contributions, including a symposium summary, Table of Contents, glossary and index.

The symposium covered comprehensively agriculture's involvement with water: conservation and management of supplies, hazards to water quality and some means of controlling them, and urban erosion control where rural erosion control practices are finding application. Those concerned with non-agricultural aspects of water resources should gain valuable insights from these symposium papers.

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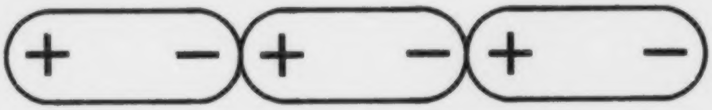

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WATER RESOURCES UTILIZATION & CONSERVATION IN THE ENVIRONMENT

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FOREWORD

Water Resources, Utilization and Conservation In The Environment is a compilation of papers presented at a symposium held at Fort Valley State College, Fort Valley, Georgia, February 28 - March 1, 1974. The objectives of the symposium were to assemble knowledgeable persons from state and federal agencies, industry, institutions of higher education, and from the private sector of our population for their interactions and ideas in assessing our water resources and their use; and who have the stewardship responsibility for maintaining and enforcing water quality standards.

Water, an international solvent and natural resource, has wide utility in both the developed, and underdeveloped areas of the world. Although the papers presented by authors are essentially related to the Southeastern United States, they have relevancy to the entire country. Daily water needs in the United States are in excess of 595 billion gallons, and this figure is expected to increase by at least 33% by the year 2,000 as population increases and technological developments intensify. Thus, it would appear logical that considerations of water for the future should be initiated with planning the watershed.

Development of the watershed involves a multitude of socioeconomic activities, including the use of water as a source of food and fiber production, as a source of energy for industry, trafficways for commerce, recreation and numerous other purposes. Community water resources correlated with development requirements offer an interesting challenge.

Since soil-water-plant interrelationships are vastly important, an appraisal of water resources must of necessity involve consideration of soil characteristics and indigenous vegetation. However, not to be neglected are the possibilities for superimposing various plant and animal species upon the environment, or the development of adaptable ones thru environment modification, breeding, and introduction, fostered by judicious water use. Therefore planning the utilization and conservation of water resources encompass surface depressions that may facilitate both temporary and permanent water storage, or drainage, and their utilization for forestry and agricultural production, and as a source of irrigation water in areas of low and erratic rainfall.

Historically, our approach has been free access to water supplies, and their use for disposal of waste materials. Bio-waste and waste-water disposal on agricultural land offer many advantages because they contain plant nutrients that will promote the growth of economic plants, and the water may be recycled. However, since the wastewater also contains heavy metals that may have diverse effects on plants and animals, it is essential that potential harmful effects be thoroughly researched. The management of pesticides, herbicides, insecticides, and rodenticides in the environment constitute a broad range of problems in the determination of their effects on ecosystems. The broad spectrum of problems related to the economy of applied plant nutrients in crop production and their occurrence in water supplies as a result of surface runoff and subsurface drainage suggest exciting areas for investigation.

Apparently we have reached a point in our development where priorities in the use of water must be considered from an economic as well as environmental conservation point of view. The publication emanating from a thorough treatment of the subject by the contributing authors, with many suggestions for research, should be an invaluable reference for research scientists, college and university professors, industrialists, regulatory personnel, and others who are vitally concerned with the use and conservation of water in the biophysical environment.

M.C. Blount

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PREFACE

Quality water, a mode of transportation for man, machine, and nutrients; a nutrient, a solvent, a cleanser, a hydrator, and integral part of energy storage, a coolant for man, beast, machine and plants; and a source for recreation, is threatened with extinction. Contamination or misuse of our water resources has awakened and aroused citizens. However, to believe that water pollution is a creation of 20th century affluent society is false, for one has only to look at the Ganges River of India or the water supply of much of Europe to see age-old water problems. Canada and the United States are among the few nations on the face of the earth where quality drinking water can be obtained from subsurface supplies.

The rapid growth of the southeastern United States in population, associated industry and renewed agricultural potential created an atmosphere of real concern among all participants. Even in a climatic zone that receives 50 or more inches of precipitation annually, frequent water shortages and/or droughts occur. The need for more and new sources of food production has created a demand for drainage or irrigation technology beyond that now in existence. Neither can take place without placing some other aspect of the water environment in danger of potential stress. Effective and efficient water use on the part of all consumers of this vital resource can dramatically alter the economy of the region. The release of water materials of all types into our water supplies from human, industrial and agricultural resources must be properly attuned to the protection of the private and public rights of all our citizenry.

Management was the key word of this symposium as papers were presented across a broad spectrum of pertinent subjects related to the water resources of the southeastern United States. The program was designed to place the several components of water management into proper prospective, away from sensationalism and scare tactics used by some to arouse public distrust of all commercial water uses. If the reader of the following manuscripts only keeps in mind the lead position he himself plays (MANagement) in water management this symposium will have been successful. In his lead position MAN will determine the quantity and quality of water to be had in support of life as we now know it on the planet Earth.

All participants are due a special bit of gratitude for their open and informative discussion of the problems which will hopefully stimulate further interest, liaison and research in a vital area of concern in the development of the southeastern United States. They are to be complimented on their insistent use of data based on sound research findings.

Special thanks should go to all supporting institutions but in particular to the staff of the Division of Agriculture at Fort Valley State College, for their persistence and determination in making this a successful symposium.

Although these are original manuscripts of the authors a cursory review has been accomplished by the editor.

William L. Colville
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and
Chairman, Division of Agronomy
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M.C. Blount
Chairman, Symposium Committee

Chapter 1

INTRODUCTION

M. C. Blount

The United States is divided into several physiographic regions, or soil provinces, each being the product of its climate in most instances. Although climate has been the most dominant, in some cases, its affect has been altered by other genetic factors of soil formation, and consequently, each region has been endowed with certain comparative advantages for the production of agricultural commodities, as well as commercial development.

In the Southeastern region, depending upon the Criteria of assessment, we may be blessed with a plentiful supply of fresh water, or cursed with relatively high annual precipitation, poor distribution, and soils generally of low inherent fertility. Regardless of the particular point of view, water is an indispensable resource that permeates all aspects of society, and affect every man, woman, and child. Many have taken for granted its abundant availability, in quantity as well as quality. Those less fortunate have learned to respect its value and the need for sound and conservative management of the supply. Many have suffered the devastation of floods and experienced the costly burden of measures for flood protection.

Water is absolutely vital to agriculture. Further, agriculture assumes a most important role in the total water picture. Over 70% of the total annual precipitation that falls on the United States is withdrawn in evapotranspiration. About 25% of the continental precipitation is evapotranspired from productive agricultural land. Equally significant is the interface between urban and agricultural interests that revolves around water. Development of rural water resources permits recreational uses by urban and rural residents alike, and may affect urban expansion. Decisions on optimum use of available water resources must strike a balance between a variety of interests that encompass all segments of the population.

Nearly one-fourth of the water used at present in the United States for domestic, industrial, and agricultural purposes comes from ground water. Withdrawals are expected to increase from 52 million acre-feet per year to over 100 million acre-feet in 1977. While ground-water resources are ample in some sections of the United States, serious over-drafts are occurring elsewhere. If ground-water resources are to be fully utilized, then a major effort in developing technology for ground-water recharge is required.

Water quality is an important aspect of the broader concern with the quality of the environment. While evaluating the environment it is recognized that evaluation of problems with water and watershed cannot be divorced from consideration of water quality. Sediment, plant nutrients, pesticides, salt and wastes from livestock enterprises all can degrade water quality. Domestic sewage, processing wastes and heat are pollutants from non-agricultural management that may be moderated by agricultural management.

Notwithstanding an abundant overall water supply, many problems are caused by water shortages; others, by excesses. Plans for water resource development or management must take account of local as well as regional and national needs. They must consider the needs of both rural communities and urban centers. With increasing urgency, they must consider multiple purposes and their interactions.

More than 44 million acres of land were irrigated in the United States in 1965. Of the 30 percent of the precipitation that reaches the streams or ground-water of the continental United States, about one-forth is actually withdrawn for use in irrigation, industry, and municipalities. Less than 1/3 of the water withdrawn, or about 100 million acre-feet, is actually consumed; about 90% of this is used by agriculture. It is estimated that, on the average, over 50 percent of the water applied on the farm runs off or is lost to deep seepage, most of the loss being by subsurface flow.

Use of supplemental irrigation for crops grown in humid areas of the United States is increasing. The advent of mechanical harvesting increases the importance of irrigation. Present investment in land, equipment, fertilizer and agricultural chemicals add incentive for use of supplemental irrigation to insure high yields and crop quality.

In the humid areas erratic rainfall distribution, water losses from seasonally excessive or high intensity rains, low water holding capacity of soils, and peak moisture demands by crops combine to make irrigation desirable or necessary for many crops. Shallow crop root zones and irregular topography in part of the humid area reduce the possibility for wide-scale land leveling for surface application of irrigation water. Inhospitable root environment in the subsoil sometimes limits rooting depth and proliferation and necessitates supplemental irrigation. At the same time rainfall following irrigation often reduces the effectiveness of applied water and causes drainage problems.

Drainage of agricultural land has long been recognized as an important factor in increasing the efficiency of crop production. It is estimated that well over 100 million acres of land in the United States need to be drained.

Wetlands occupy about 70 million acres of the nation's land surface. They include bogs, swamps, marshes, wet meadows and tidal flats. Lands with excess water have realized or potential value for many purposes, including tree production, recreation and use for wildlife habitats; they may be useful for storing water supplies for other purposes.

Water in the Southeast presents the region with both problems and opportunities. Increasing population will cause increased pressures on all regional resources, especially water. Although considerable information on water is available, there is no single volume that inculcates multiple approaches and research needs on water resources, utilization and conservation in the Southeast.

Fifty centuries ago the Mohan-Jo-Daro Civilization in India enjoyed the benefits of well designed water supply and drainage systems.

The people of Assyria, Babylonia, Egypt, Israel, Greece, Rome, and China built similar facilities long before the Christian era.

Hammurabi, Babylonia's king, supervised the digging of an extensive network of irrigation canals and promulgated laws for their repair.

Hippocrates recognized the dangers to health of polluted drinking water and recommended that it be filtered and boiled.

Mohammed saw water as an object of religious charity. He passed laws that made all families along a watercourse responsible for its cleaning and costs in proportion to its irrigation rights.

In 1800 the Timber Conservation Acts were passed in the United

States; in 1972 the Sedimentation Acts.

Today we are gathered for an assessment of the past, analysis of the present, and planning for the future use of water. Represented in this group are individuals with diverse backgrounds, from many institutions and agencies, each having a different philosophy of the wisest course of water use; but all concerned with socio-economic problems. Perhaps it is fitting then, that as we seek to gain insight into the problems and successes of others, and hopefully, develop new outlooks with respect to water, this activity should take place at an emerging institution, which heretofore has not enjoyed a role of prominance characteristic of the larger land grant Colleges and Universities.

Since numerous references occur in the literature as utilized in the foregoing, no attempt was made for citations.

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THE ROLE OF THE WATERSHED IN HYDROLOGIC RESEARCH

Walter G. Knisel, Jr.

ABSTRACT

A sample of the evolution of technology in hydrologic research in the ARS is presented. The phases are traced from the demonstrational-type research, to the paired watershed concept, to the simple regression models, to parametric hydrology. The parametric hydrology approach of the SEWL is presented to show how watershed research data are used for information factoring. A 5-day water yield model is cited as the basic technique for building information sets.

Chapter 2

THE ROLE OF THE WATERSHED IN HYDROLOGIC RESEARCH

Walter G. Knisel, Jr.

INTRODUCTION

Hydrology is a relatively new science as compared with some of the other scientific fields. A number of hydrologists would argue that hydrology is still more of an art than a science; nevertheless, there has been considerable progress towards development of the science in the last several years. Since hydrology embraces many separate sciences, it is not a self-contained discipline. Its concern is with the occurrence and movement of water into, through, and out of the atmosphere; over, into, through, and out of the soil; into, through, and out of the streams. Is it little wonder then, that the putting together of the several sciences has been claimed to be an art?

Across the nation, diviners still practice the art of dowsing or water witching for locating groundwater (Todd, 1959) and a number of weather "forecasters" know when it is going to rain by their arthritis or bunions. However, hydrology is much more scientific than these artful feats, although some of its aspects have not been fully developed.

The first British book on hydrology was written by a civil engineer, Nathaniel Beardmore, in 1862 (Chow, 1964). The first American book, entitled Notes on Hydrology, was written by Daniel W. Mead who was the first to teach a university course in hydrology at the University of Wisconsin, in 1904 (Chow, 1964). However, not until Meinzer (1942) published his book, did hydrology texts begin to flourish. The 1940's texts began to cite the early plot studies of the erosion experiment stations in the 1920's and 1930's, and the first studies of agricultural watershed research by the Soil Conservation Service, Research Division, in the 1930's. Hydrologic research of the 1920's and 1930's was not the first, but it was the forerunner of our present agricultural watershed research.

A brief review of the role of the watershed in research shows how science has developed over the years to the present-day technology. This discussion does not imply that the predecessors of the Agricultural Research Service were the originators of watershed research. The old Soil Erosion Service initiated plot studies that provided runoff and erosion data for specific purposes. However, the U.S. Geological Survey has been measuring streamflow from large, mixed land-use watersheds (river basins) for many years. Their streamflow measurements and research were valuable in water resources development, but they did not provide information on small agricultural areas. The Forest Service, also, has been conducting hydrologic research and their scientific contributions are recognized as highly important in the overall scientific effort. However, my familiarity with hydrologic research in ARS provides a number of specific examples of changes in watershed technology which will be used to document these time changes.

PLOTS AND SMALL WATERSHEDS

In the 1920's and 30's, 11 erosion experiment stations were established in major agricultural physiographic areas in the humid, subhumid, and semiarid areas of the United States, east of the 100th Meridian. Among the original erosion experiment stations, the only currently active stations are the Southern Piedmont Conservation Research Center at Watkinsville, Georgia, the Blackland Conservation Research Center at Temple, Texas, and the station at Bethany, Missiouri (Claypan area).

The erosion experiment stations established many fractional-acre plots with different slopes and different cover. Rainfall was observed, and runoff and soil loss were measured from the plots. The research consisted of comparisons of surface runoff volumes and erosion for the different slopes, slope lengths, and land-use. The erosion data, however, were not fully utilized until 25 to 30 years later. In addition to the fractional-acre plots, many small so-called watersheds of 1 1/2 to 5 acres were established for runoff and erosion measurements. The plot and small watershed data were used in developing design criteria for terrace systems and farm livestock water supply ponds. Like plots, the small watersheds were considered only for the surface runoff, or overland flow. The soil scientists and engineers involved in the studies were concerned only with what they could see on the land surface. Although they were aware of the other phases, they measured only what they saw.

Most "analyses" of the "hydrologic" data consisted of minutely describing cover and soil conditions and expressing the runoff as an equivalent depth of water over the plot or watershed surface. The equivalent depth of runoff was expressed as a percentage of the rainfall for each storm; i.e., Q/P, where Q is the depth of runoff in inches and P is the depth of rainfall in inches. As expected, these percentages varied widely depending upon land-use and soil type. For a particular cover, the runoff may have ranged from less than 1 to more than 90 percent for heavy, montmorillonitic clay soils.

Because of the limited soils ranges at an individual experiment station, little attention was given to comparing soils in physiographic areas. Eventually, the differences in performance between soil series were realized and bare plots were maintained to compare soils.

The plots and small watersheds were used advantageously as building blocks in the learning process. Specifically, these data were used to design terrace systems, terrace outlet channels, farm waterways, farm ponds, and hydraulic structures. They provided information that stimulated soil and water control practices. However, these plots and small watersheds were inadequate for testing field-scale practices.

EXPERIMENTAL WATERSHEDS

In the mid-1930's, experimental watersheds were established by the Soil Conservation Service, Research Division, at 3 locations in the United States--the North Appalachian Experimental Watershed at Coshocton, Ohio, the Blackland Experimental Watershed at Riesel, Texas, and the Central Great Plains Experimental Watershed at Hastings, Nebraska. The watersheds at Coshocton and Riesel are still in operation.

At each of these experimental sites, a number of natural watersheds were delineated with areas ranging from approximately 3 to 6,000 acres.

The smallest areas provided a tie with the old erosion experiment station plots and small watersheds. Intensive measurements of rainfall, runoff, streamflow, and soil loss were established. Intensive geologic and soils, and topographic surveys were made. Interpretations of these data were used to develop intensive networks of groundwater observations. The information and data sets developed at these experimental watersheds were very complete, and still represent some of the best hydrologic data in the world (USDA, 1942).

The experimental watersheds were established with the concept of paired watersheds where watersheds of similar size, shape, soils, geology, topography, and land use were selected in pairs. During a calibration period, the hydrologic response was measured to determine any inherent differences between watersheds receiving the same treatments. After the calibration period, one watershed was treated with some recommended land use and conservation practices, while the other watershed was maintained in the untreated condition. Differences in hydrologic response, beyond the inherent differences, could be ascribed to treatment effects, which was the foremost premise of design with a paired-plot analysis (Snedecor, 1953). Each storm event provided data points for the watershed pairs so that direct comparisons of runoff could be made.

In addition to the paired statistical analysis, graphic analysis was made. One of the most common graphical analysis is the double mass curve (Figure 1), where watersheds are compared (Baird, Richardson, and Knisel, 1970). The line in Figure 1 shows a change in slope beginning in 1943 after the conservation practices were applied on watershed Y-2. The end point in 1960 has 131.4 inches of accumulated runoff from W-1

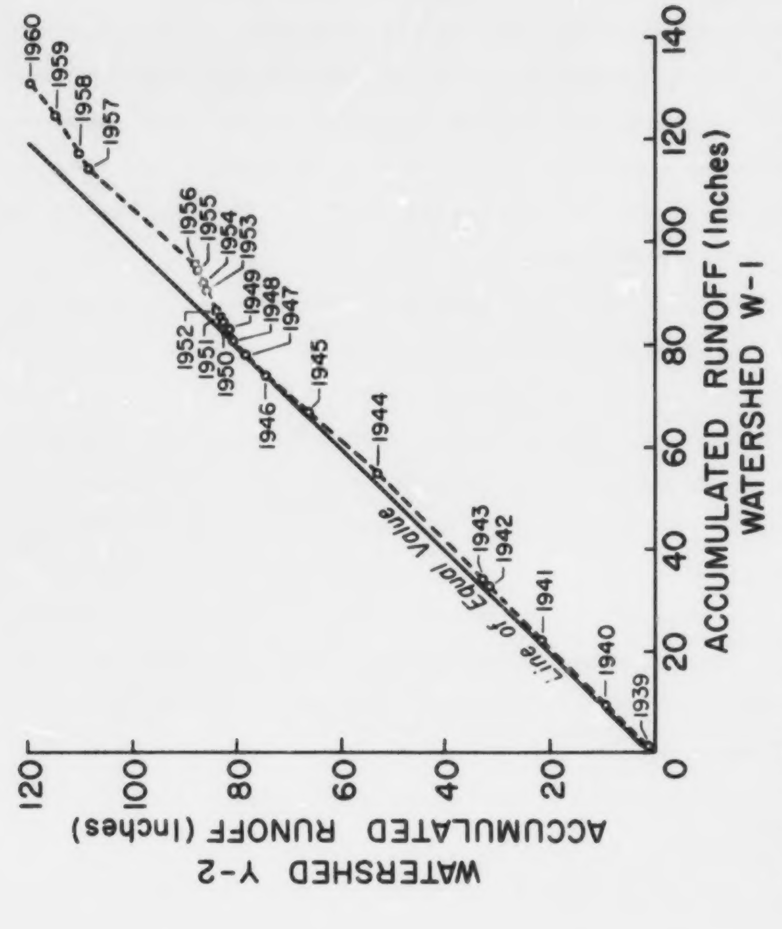

Fig. 1. Double mass curve of runoff for watersheds W-1 and Y-2, Blacklands Experimental Watershed, Riesel, Texas.

and 119.8 inches from Y-2. This is approximately 0.6 inch per year less runoff due to conservation practices. Where the points are spaced far apart, the two watersheds differ little; i.e., in wet years, conservation practices have little or no effect. The real effect occurred in dry years (shown by the closely spaced points). The rainfall element is omitted in the double-mass plot of accumulated runoff. To ascribe all of the indicated difference in runoff to effects of conservation practices, the rainfall must be the same. A similar type of plotting must be made for rainfall to compare totals, but the differences in rainfall probably occur in individual storms.

These were not the only analyses made for the experimental watershed data. Among others were sediment yield (Baird, 1964), peak rates and frequency analysis (Baird and Potter, 1950).

Although paired-watershed analysis is a powerful simple technique, it does not give much information about the underlying hydrologic processes. Also, complicating factors often cause difficulty in interpreting results (Hornbeck, 1973). Only single variables or single combinations of variables can be compared in such analyses.

Variations of the straight statistical paired-watershed technique have been applied. Because of differences in rainfall between watersheds, Baird, Richardson, and Knisel (1970) used storm rainfall retention; i.e., rainfall minus runoff, and developed a regression equation to determine effects of conservation practices. The equation was

$$(P-Q)_{y-2} = a + b\ (P-Q)_{w-1} \qquad (1)$$

where P is precipitation in inches, Q is runoff in inches, and a and b are regression coefficients. Equation 1 was transformed to give

$$Q_{y-2} = P_{y-2} - a - b\ (P-Q)_{w-1} \qquad (2)$$

Equation 1 was developed for the calibration period and again for the treatment period. The calibration equation established the relation for any inherent watershed differences. The treatment equation established the treatment effect plus the inherent difference. Then equation 2 was applied to a given period with (a) watershed Y-2 as an untreated watershed and (b) watershed Y-2 as a treated watershed. The computed differences in storm runoff, a 24 percent reduction, were the effects of conservation treatment. This is twice as great as the 10 percent reduction obtained by using total runoff, irrespective of rainfall (Figure 1).

ERA OF THE COMPUTER

Development of the electronic digital computer in the 1950's made possible significant advances in the science of hydrology. Numerical analyses, multiple regression, optimization, and other mathematical procedures that require many tedious calculations could be performed quickly on the computer. Hydrograph analysis (Snyder, 1955) became more exact, and the first mathematical models were developed in ARS for runoff prediction (Hartman, et al., 1960; Hamon, 1963).

Multiple Regression

In the 1950's, ARS, SCS, and the Bureau of Reclamation cooperatively studied the effects of land use and treatment on streamflow

(Sharp, Gibbs, and Owen, 1966). Data for several watersheds over a large range in size in the Great Plains were analyzed. A total of 19 variables were considered in an attempt to develop a rational procedure for estimating land use effects on annual streamflow. All 19 variables were not considered simultaneously nor were all of the variables truly independent. The very different conditions over which the procedure was applied caused such great variability that a significant multiple regression equation could not be developed.

Erosion data from plots and small watersheds had been collected since the late 1920's. The volume of data was so massive that a computer was needed to consider all available information. In 1956, a concerted effort was initiated to develop a universal soil loss equation. Correlation and regression techniques were used (Wischemier and Smith, 1965) to analyze the volumes of data available. The presently used universal soil loss equation was developed to predict annual source erosion. The equation is

$$A = RKLSCP \qquad (3)$$

where A is the average annual soil loss in tons per acre, R is the rainfall factor, K is the soil erodibility factor; L is the slope-length factor; S is the slope-gradient factor; C is the cropping and management factor; and P is the factor for conservation practices. The equation has been used widely for comparing erosion potential for various land use and treatment practices. At Lafayette, Indiana, the prediction technique was refined by considering other factors and by analyzing new data that have been amassed over the years. This is one of the more fruitful efforts of ARS model development. In addition to the scientific expertise applied, two main reasons for the relative success of the effort are: (1) availability of the digital computer, and (2) availability of masses of data.

For many reasons, large volumes of data are necessary to accurately quantify physical hydrologic processes. The random occurrence of rainfall in time and space and the amount of precipitable water in the atmosphere are such that a storm event never exactly repeats itself. Also, the landscape, or watershed, is truly dynamic. The combinations of factors influencing runoff and erosion are never exactly duplicated. Soil water content changes continually. Groundwater status is transient. Land cover is constantly changing, thus changing evapotranspiration. Soil condition, even under continuous grass cover, changes with time. Wetting and drying cycles, tillage, continued grazing of grassland, soil organism activity, chemical reactions in the soil, and atmospheric conditions are all interacting factors that affect the hydrologic response of a watershed to a rainfall event. It would be physically impossible to exactly duplicate all the interacting factors in mathematical expressions. Therefore, it is necessary to average over a number of factors. Since a few factors may dominate in hydrologic response of an area, this works to the benefit of the hydrologists.

Runoff Volume Models

Hartman, et al. (1960) found that soil water content when a storm occurred was the most important factor in predicting storm runoff volumes. Relationships were developed between precipitation, runoff, and antecedent soil water. Figure 2 shows the parabolic rainfall-runoff relationships derived. Although these relations were developed from data for watersheds of single land use where soil water data were available, they hold for all land uses. The difference in runoff from

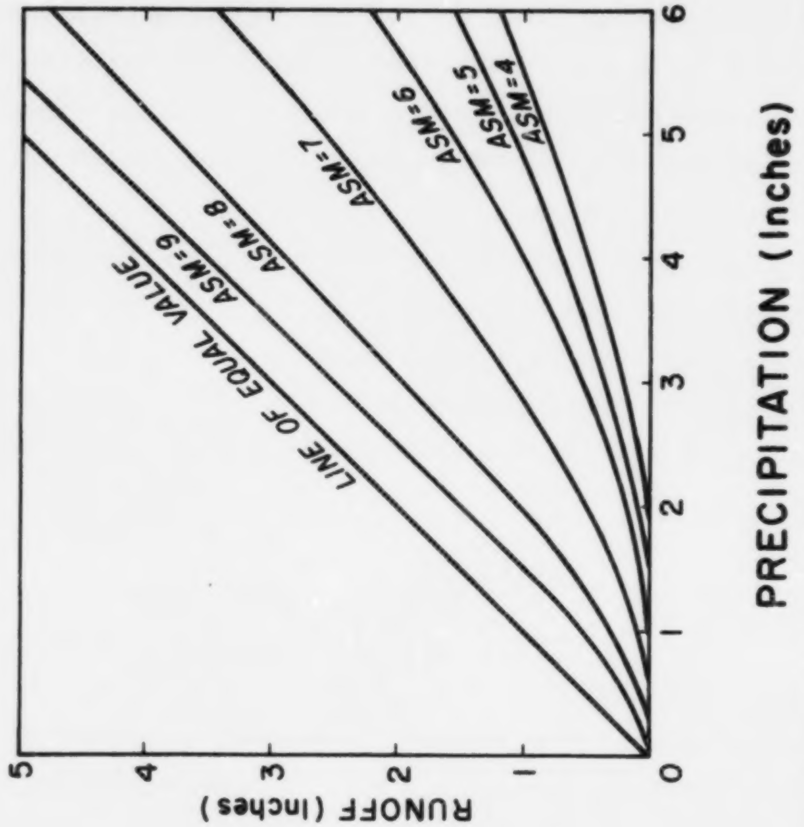

Fig. Rainfall-runoff-soil water relation, Blacklands Experimental Watershed, Riesel, Texas.

different land uses results in different antecedent soil water content when storms occur. Soil water accounting procedures were developed to consider land use and season in estimating evapotranspiration--and thus soil water depletion--between storm events. The model was developed for a specific purpose for a specific land resource area. The procedure is directed toward prediction of runoff volume in a land resource area where groundwater and baseflow are nonexistent and storm runoff is synonomous with water yield.

The Soil Conservation Service needed to develop a runoff prediction technique irrespective of land resource area. Rainfall and runoff data from all possible sources were used in the development of a model that considered soil type, land use and treatment practices, and antecedent rainfall (US Department of Agriculture, 1964). The equation for runoff is:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad (4)$$

where Q is runoff in inches; P is precipitation in inches; and S is the potential maximum storage in inches. S is a function of antecedent moisture and soil-cover complex. A family of curves was developed for equation (4) by the relation:

$$CN = \frac{1000}{10+S} \qquad (5)$$

where CN is curve number. Curve numbers are determined by soil, cover, treatment, and antecedent rainfall. The SCS procedure was averaged over all land resource areas, and as would be expected, is less exact than desirable for extreme conditions. The method is very creditable, and probably would be much more accurate if research data were available. At the time the method was developed, existing data were not sufficient for many land resource areas.

ESTABLISHMENTS OF WATERSHED RESEARCH CENTERS

In 1959, the late U. S. Senator Robert Kerr of Oklahoma, Chairman, Senate Agriculture Committee, initiated a series of hearings across the nation to determine research and facility needs in soil and water conservation. As a result of these hearings, a report of these needs and Senate recommendations were published. USDA, Research Senate Document 59 (1959) became the basis for congressional appropriations toward establishment of the needed facilities. One of the needed research facilities established, the USDA Sedimentation Laboratory at Oxford, Mississippi, is responsible for sediment transport and sediment yield on a national basis. Obviously hydrologic research is an integral part of field sedimentation research. However, since sedimentation represents a topical area in itself, it will not be treated here.

Among other needed facilities for watershed research in the U. S. were:

(1) Southwest Watershed Research Center at Tucson, Arizona
(2) Northwest Watershed Research Center at Boise, Idaho
(3) Southern Plains Watershed Research Center at Chickasha, Okla.
(4) North Central Watershed Research Center at Columbia, Missouri
(5) Northeast Watershed Research Center at University Park, Penn.
(6) Southeast Watershed Research Center at Athens, Georgia.

The Southeast Watershed Research Center, the last to be established (1966), has responsibility for hydrologic research in the Coastal Plain and Coastal Flatwoods of the Southeastern United States. The principal research watershed is the Little River Watershed at Tifton, Georgia, with other research watersheds at Ahoskie, North Carolina, and Okeechobee, Florida.

Each of the research centers was faced with specific problems peculiar to the respective areas. Their common main objective was to develop methods to predict runoff from ungaged watersheds. Action agencies are requested to plan water resources development in watersheds where little or no data are available. Availability of data is generally limited to Weather Bureau daily precipitation records, often for locations outside the watershed. The research watersheds provide valuable data for development of techniques (models) that can be extrapolated to ungaged areas.

PARAMETRIC HYDROLOGY

In modern terminology, hydrologic models have been described as deterministic, parametric, or stochastic. In the deterministic approach, equations are written to describe the hydrologic processes. In the strict definition of determinism, data are not needed to establish coefficients in the equations. Rather, soil properties, topography, etc., are all that are necessary to determine the coefficients. This method is sometimes confused with empiricism where equation coefficients are derived from data. Stochastic hydrology deals with the probabilistic occurrence of events and sequences of events in time. In parametric models, concepts of macro-scale hydrologic processes are cast into mathematical formulation. Then input (rainfall) and output (streamflow) data are substituted into the formulations to determine the numerical parameters.

The Southeast Watershed Laboratory uses the parametric approach to hydrologic research. This is not intended to indicate that the scientists disagree with the proponents of deterministic and/or stochastic approaches, but merely represents the choice of approach. The parametric approach is not only directed towards development of parametric models, but is used as a method of data processing and a process of information factoring. The research watersheds are considered as soil-water systems which they truly are.

One of the first developments in parametric hydrology in the Southeast Watershed Laboratory was the development of a nonlinear water yield model (Snyder, Mills, and Stephens, 1971). The model was conceptualized as consisting of three components--a characteristic function, a state function, and a seasonal loss function. The characteristic function represents the physical characteristics of the watershed expressed as a potential for water yield. The state function represents the transmission of the potential yield to the watershed outlet. The seasonal loss function is used to diminish the input rainfall to produce 5-day amounts of rainfall effective in production of streamflow. The model is operated in the following manner: the state function is convolved (matrices multiplication) with the characteristic function to produce the unit-yield function; the seasonal loss function is applied to reduce total rainfall to effective rainfall; and the unit-yield function is convolved with the effective rainfall by

5-day periods to produce 5-day streamflow amounts.

To show how parametric modeling is used to abstract information, the components of the 5-day water yield model should be examined. This presentation relates to the model as developed in 1971. Since rainfall is the input to the system, the seasonal loss function will be considered first. All rainfall received at the earth's surface does not go to streamflow. Some is retained in the soil profile and later evaporated or transpired. When soil water content is high, some rainfall will percolate through the profile to the groundwater; i.e., some rainfall is "lost" as far as streamflow is concerned. For this particular model, the important item is that rainfall is partitioned between streamflow and nonstreamflow. Since evapotranspiration is controlled by the cyclic march of incoming solar energy, the seasonal loss should be cyclic. The groundwater recharge, or deep percolation, is a function of rainfall as well as ET, and therefore is superimposed on the cyclic ET relation. Such a function was conceptualized and, through optimization, the loss function derived is shown in Figure 3. The continuous line shows the cyclicity.

As stated above, the characteristic function represents the ability of the watershed to receive and store rainfall for future delivery to the watershed outlet. The function is static in that it remains unchanged for each 5-day period in the record. It would be a unit-yield function under the idealized situation of passage of a unit input of water from the watershed with no attenuation. The function is form-free with ordinates determined at 1, 2, 3, 5, and 15 5-day periods with specification of zero at the 30th period. The function, determined by optimization techniques and linear interpolation, is shown in

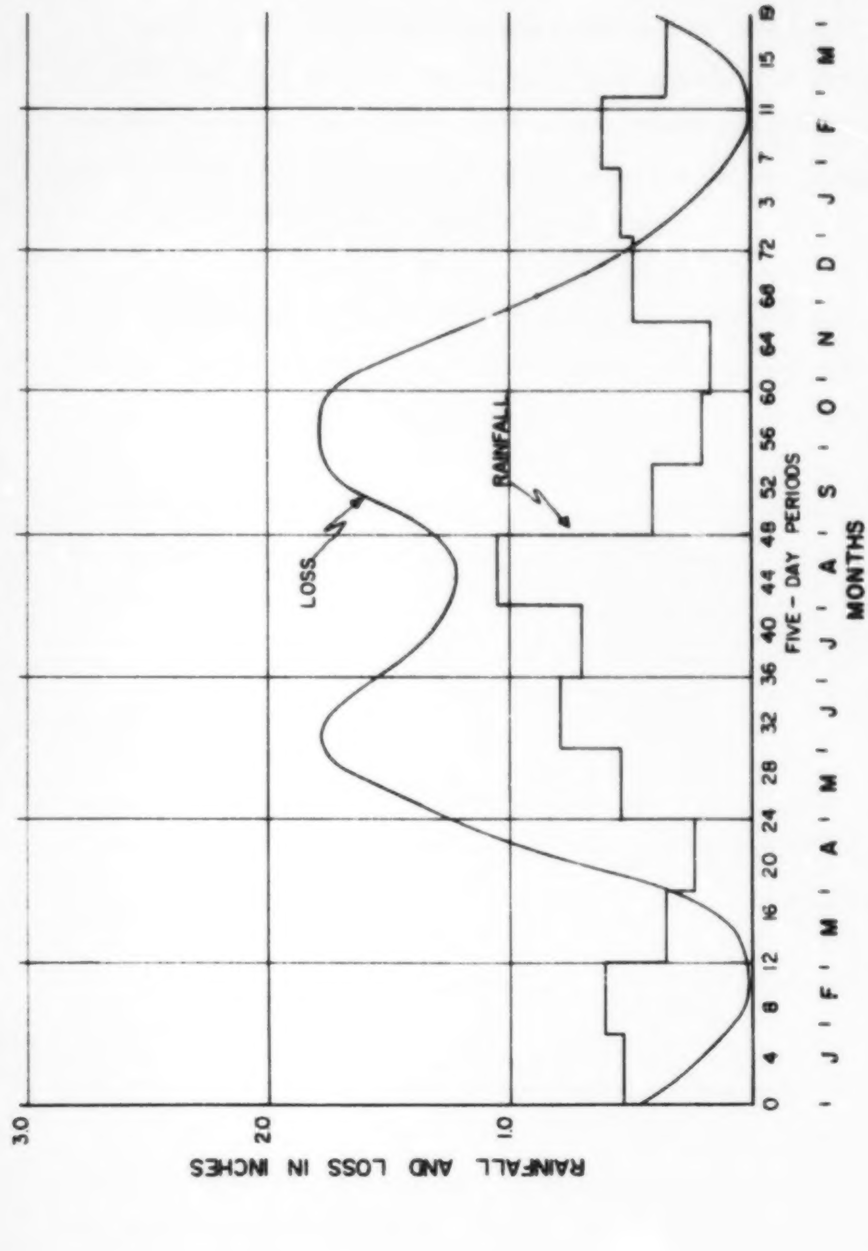

Fig. 3. Seasonal-loss function, Ahoskie Creek, North Carolina.

Figure 4. Physically, the characteristic function represents a combination of factors, such as soil type, soil depth, soil water storage capacity, infiltration as affected by soil cover complex, hydraulic conductivity, topography, and geologic conditions. Since the watershed is able to receive and store water, Figure 4 might be viewed as follows: Most of the total storage would be filled in the first 5-day period, a lesser amount would be filled in the second period. etc.

The state function routes the characteristic function to the watershed outlet with storage attenuation. Since the storage attenuation depends on the amount of water already in storage, the function can be considered to represent the wetness of the watershed. That is, if the watershed is "wet," there is little potential for storage attenuation and additional rainfall will move rapidly to the watershed outlet. The state function can be expressed as

$$S(t) = \frac{1/t_i^{\,m}}{\sum_i 1/t_i^{\,m}} \qquad (5)$$

where t is time in 5-day periods, and the exponent m is determined by regression as

$$m = b_1\ (5.0\text{-PPR}) + b_2 \qquad (6)$$

PPR is the streamflow in the previous 5-day period, and b_1 and b_2 are regression coefficients.

Model operation consists of convolution of the characteristic function and state function to produce a variable unit-yield function

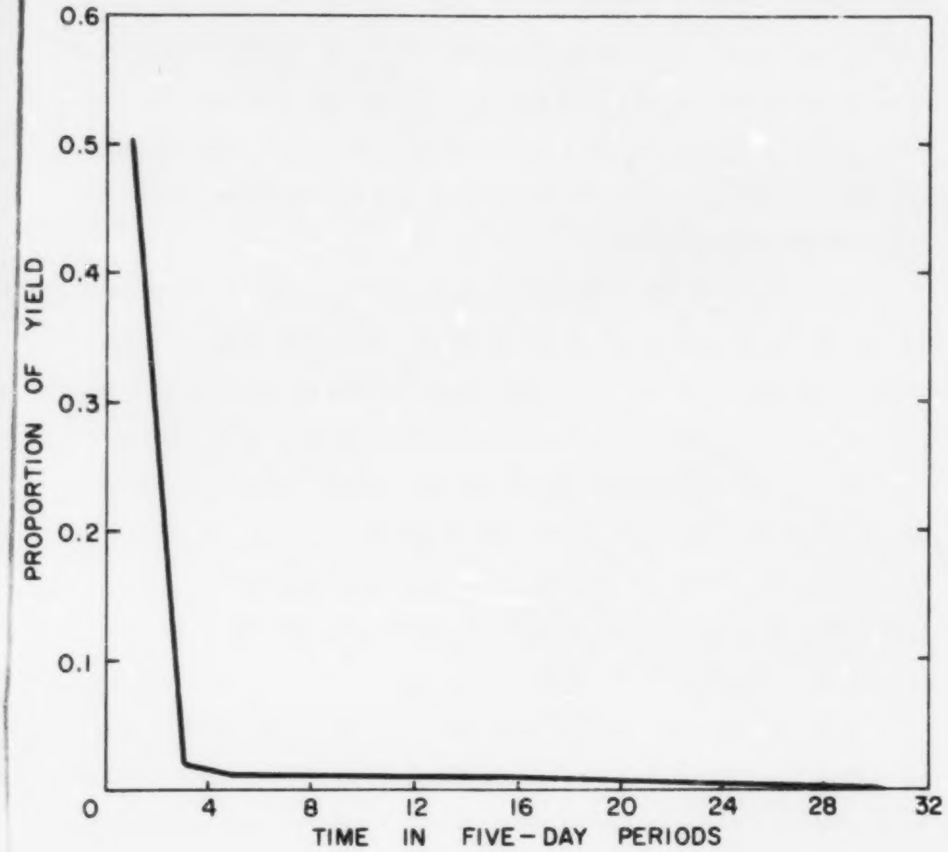

Figure 4. Characteristic function, Ahoskie Creek, North Carolina.

(Figure 5). Variable nature of the function is depicted by the different lines for different antecedent conditions. The unit-yield function is somewhat analogous to the unit hydrograph in storm runoff. Total rainfall by 5-day periods is diminished by the seasonal loss function to produce the amount of rainfall that becomes streamflow. The effective rainfall is convolved with the variable unit-yield function to produce the 5-day volumes of runoff.

The details of the model given above are necessary to show how information from analysis is used to gain further information. For example, the model as explained is related to fitting historical data. How can the model be used to predict future response on the same watershed or another ungaged watershed? Through regional analysis, some of the parameters may be mapped. The seasonal loss function as presented may be determined regionally as functions of climate. The characteristic function is a composite of an infinite number of point functions.

Work is underway to map a watershed, by sampling a finite number of points, by considering the combinatorial factors previously mentioned. Regression coefficients may be determined through regional analysis.

Any model or research finding, particularly in hydrologic studies, is not an end in itself. A recent development was started to incorporate another feature into the so-called loss function. Obviously the loss includes soil water storage to make up any deficiency that may exist at the time of rainfall. As such, some of the "not streamflow" portion represents refilling available storage. Therefore, an available storage term was incorporated into the model. This leaves the deep percolation or groundwater recharge portion. Recharge to groundwater

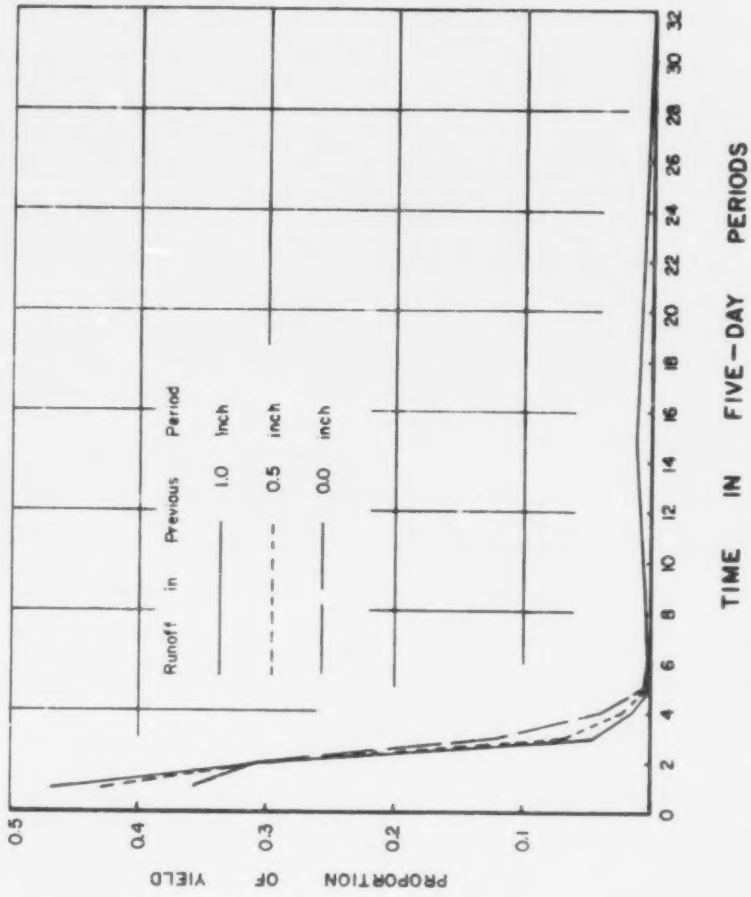

Figure 5. Unit-yield function, Ahoskie Creek, North Carolina.

may represent two phases: some subsurface movement that reappears as streamflow and some that recharges a regional aquifer that does not reappear as streamflow. Recharge does not occur instantaneously, and groundwater-observation well records reflect the timing. An effort is underway to develop a parametric groundwater model similar to the water-yield model. It uses information from the water-yield model and further partitions the "not streamflow" portion of total rainfall. These developments provide an opportunity for interface with water management. The soil water storage and groundwater phases are of interest in irrigation needs and opportunities. The soil water storage is equally important to soil and water management specialists in developing crops and cropping systems for more efficient use of our important water resource.

Since the water yield model appears appropriate in streamflow estimation and since water is the carrier of sediment and chemicals, the model has other potential uses. A sediment-discharge rating was applied to the water yield model, and the first-round results indicated feasibility that the model could estimate sediment volume. Although a chemical discharge rating is more tenous, a similar incorporation may be possible.

RESEARCH NEEDS

To enumerate the many research needs in watershed hydrology would require another paper as long as this one. Therefore, the research needs included here are centered around the 5-day water yield model.

Parametric modeling efforts in the Southeast Watershed Laboratory are cast into two modes: analysis and simulation. Both modes of operation are relative to the research watershed. To extend the models to ungaged watersheds, some physical measurements are necessary to quantify model parameters. Field research is needed to develop sampling techniques for estimating the watershed characteristic function. All the work thus far has been by derivation of the function through input-output analysis; i.e., using observed rainfall and observed streamflow data to derive the function. Field methods of identification of the combinatorial factors are needed to determine the characteristic function when input and output data are not available for the watershed of interest. Field sampling has contributed towards this development, and progress has been made. However, more research is needed to develop techniques for determination of the "time map" of the watershed. This is considerably different from normal mapping of soils, topography, land use, and geology.

SUMMARY

The modeling developments and extensions described are not the only efforts in parametric hydrology in the Southeast Watershed Laboratory, and considerable future effort is needed. However, developments described indicate the changes that have evolved to give new roles to the research watersheds. The watersheds are natural outdoor laboratories from which the hydrologists learn. The learning process is analogous to use of building blocks. As we learn to build, we are able to factor useful information. Also, this learning process will help to develop hydrology as a science.

In summary, the changing role of the watershed has been shown. Progress has been made from the demonstrational approach with ratio of runoff to rainfall, to the paired-watershed concept, to the rainfall-runoff-soil moisture model, to the parametric information-factoring models. As new techniques and methods are developed, further extensions with associated feedback will help to provide more information useful in water resources planning and development.

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Chapter 3

SURFACE AND SUBSURFACE WATER SUPPLIES AND GROUND WATER RECHARGE

John L Sewell

INTRODUCTION

The Southeastern States have the highest average annual precipitation of any large area within the contiguous United States. With the exception of certain areas of the Pacific Coast and the Northeastern States, the Southeastern States also have the highest average annual runoff in the United States. Even with such great potential for water supplies, many areas within most of the Southern States experience, at least temporarily, shortages of water supplies from surface or subsurface sources.

During the 1960's, considerable interest developed in surface and groundwater yields - especially those associated with small watersheds. Several research efforts were initiated including Southern Regional Project S-53, "Factors Affecting Water Yields from Small Watersheds and Shallow Ground Aquifers." Research efforts from the state universities of GA, KY, LA, MS, NC, SC, TN, TX, VA, and PR and USDA, ARS cooperators have contributed to S-53.* Lillard et al (6) described inputs to S-53. The research reported herein and pertaining to the Southern States is an outgrowth of S-53. Since no hydrologic studies were reported for TX, such data are not included.

While little interest in groundwater recharge is yet evident in the Southern States, this could be anticipated in those areas now depending on groundwater as a source for water supplies. Three Southern States now depend on groundwater for 20% to 50% of their supplies.

SURFACE WATER

General Overview. Table I indicates that the average annual precipitation of the Southeastern States varies from 43 inches for VA to 55 inches for LA. The average annual evaporation (Table I) from open lake or river surfaces varies from 35 inches for KY to 48 inches for LA and FL. These climatic factors, with the particular local watershed conditions, result in average annual surface runoff including base flow (Table I) varying from 10 inches for FL to 20 inches for AL, MS, and TN.

The TN Department of Conservation and Commerce (11) reported the mean annual streamflow for twenty-eight major streams to be 22.3 inches, representing 44.6% of the state's mean annual precipitation of 50 inches. While the Southern States have high annual average stream-flow, this is often not well distributed throughout the year, resulting in floods and temporary shortages in some areas.

Recent Research. Contributors to Southern Regional Project S-53 have developed a series of models predicting water yields from small watersheds as a function of many independent variables including precipitation, area, topography, slope, soils, geology, temperature, geographic location, vegetation, stream channels characteristics, land use, watershed

*Contribution by Tennessee Agricultural Experiment Station Project H-204, "Factors Affecting Water Yields from Small Watersheds in Tennessee," to Southern Regional Project S-53.

Table 1. Approximate Average Annual Values in Inches of Hydrologic Parameters for the Southern States

State	Precipitation[a]	Snowfall[b]	Evaporation[c,d]	Surface Runoff [c,e]
AL	54	2	43	20
AR	47	5	43	16
FL	53	0	48	10
GA	49	2	43	15
KY	44	14	35	18
LA	55	2	48	17
MS	52	2	43	20
NC	50	8	41	15
SC	48	3	42	13
TN	49	8	37	20
VA	43	20	37	15

[a] Data from U. S. Weather Bureau (12).

[b] Data from Whisler and Brater (14).

[c] Data from Geraghty et al (2).

[d] Evaporation from open lake or river surfaces.

[e] Total streamflow from large areas; includes surface runoff and base flow.

shape, potential evapotranspiration, season of year, mean elevation, antecedent conditions, groundwater level, and others.

The models developed vary from comprehensive computerized models taking into account many hydrologic parameters including seasonal variations and requiring large digital computers for solution, to simplified models requiring only easily obtained climatic and watershed data and lending themselves easily to solution on desk calculators.

Shanholtz and Burford (8) for VA and Ligon et al (5) for SC, using procedures somewhat similar to those of the Stanford Model, developed for particular watersheds models simulating maximum flow discharge hydrographs; daily peak flow rates; monthly peak flow rates; and average daily, monthly, and annual flow volumes. The model simulations agreed with recorded data to varying degrees depending on watersheds and types of data simulated. Simulated and measured annual discharges for both studies seldom differed more than 5%. The agreement for monthly discharges was not as close. The simulation of peak flows for individual hydrologic events often agreed closely with recorded data; however, sometimes these simulations did not at all agree with recorded data.

Haan and Read (4), in a study of thirteen Ky watersheds varying between 0.67 and 7.47 square miles in area and representing the most usual hydrologic conditions of the state, found the mean annual runoff from 46 inches of precipitation to be 16.5 inches or 28%. They also developed a family of multiple linear regression equations predicting annual runoff volumes on probability bases for the individual watersheds studied. These equations predicting 16.5 inches mean annual runoff had average coefficients of variation of 0.35. While these regressions characterized the runoff from the KY watersheds well, they would not necessarily be expected to apply to watersheds of other geographic areas.

In investigations of the parameters necessary for hydrologic characterization of watersheds, Shelton and Sewell (10) found, by applying rotated factor analyses to four TN watersheds, that eleven of seventeen physical variables could be eliminated from consideration without a statistically significant reduction in information characterizing those watersheds.

Shelton et al (9) reported for eight small TN watersheds, a simplified multiple linear regression model predicting mean annual runoff as a function of evapotranspiration, elevation, area, land use, precipitation, and temperature. This model was significant at the 95% level, and the standard error of the estimate was 0.29 inches runoff. Models were also developed for yield during the dormant (Oct.-Mar.) and growing (Apr.-Sep.) seasons. The regression for the dormant season depended only on area and land use, and its standard error was 0.57 inches. The regressions for the growing season had poor indexes of precision, and current effort to improve the model involves the addition of several variables including rainfall intensity. The hydrologic data required for such models can be obtained without great difficulty, and they could be used by most technicians at the local level.

Continuous surface water supplies from streamflow are related to the groundwater-baseflow regime. Wilson and Wiser (12), in a five-year study of base flow from a 561-acre Piedmont watershed in SC, found the mean annual baseflow to be 10.2 inches of the approximately 17 inches annual runoff. The mean annual rainfall was 48 inches.

Table II presents a summary of average watershed runoff values developed under S-53. The watershed descriptions are given in Table III, and the watersheds were grouped for averaging according to hydrologic similarities. The KY watersheds which were larger on the average than any others studied produced, during the dormant season, runoff values which were 55% of the precipitation; and those during the growing season were only 16%. The SC Piedmont watershed (SC-A) produced much higher runoff than the SC Coastal Plain watersheds (SC-B).

The TN watersheds exhibited a wide range of hydrologic performance

Table II. Average Watershed Runoff Values as Developed under Southern Regional Project S-53[a]

State[b]	Number of Watersheds	Area[c]	Q/P Dormant[d]	Q/P Growing[e]	Q/P Annual	Q Annual
KY	13	2,030	55	16	37	16.6
SC-A	1	560	41	22	32	16.3
SC-B	2	31	23	8	16	7.8
TN-A	2	26	27	12	20	13.0
TN-B	2	29	2	3	2	1.1
TN-C	2	105	10	10	10	4.4
TN-D	2	38	29	26	27	13.3
TN-E	2	51	91	35	65	34.8
VA-A	6	640	36	13	24	9.1
VA-B	2	1,920	21	9	15	5.1
VA-C	2	1,460	50	22	35	12.3

a. "Factors Affecting Water Yields from Small Watersheds and Shallow Ground Aquifers."

b. See Table III for watershed descriptions. Watersheds were grouped according to hydrologic similarities.

c. Average acres.

d. Q is inches runoff, and P is inches precipitation. The dormant season includes the months of Oct.-Mar. Q/P is the percent precipitation resulting as runoff during the period specified.

e. The growing season includes the months of Apr. - Sept.

due primarily to soils, geologic, and land-use differences. The TN-A and TN-B, both Valley and Ridge Province, watersheds were 100% woods (TN-A) and 100% pasture (TN-B). While the pasture and wooded watersheds yielded 2% and 20%, respectively, of the annual precipitation as runoff, the large difference was attributed to geologic dissimilarities rather than land use or cover. The Central Basin watersheds (TN-C) in mixed row and hay crops yielded 10%. The Gulf Coastal Plain watersheds (TN-D), which were largely cultivated to row crops, produced average annual runoff

Table III. Brief Watershed Descriptions

State	Description
KY	Generally agricultural watersheds with mixed cover, representative of much of the state, limestone substrata present in many areas.
SC-A	Piedmont, sandy loam with clay subsoil extending to bedrock.
SC-B	Coastal Plain, sandy soils, water table within 5 to 15 feet of soil surface.
TN-A	Valley and Ridge, 100% forest, cherty silt loam developed over dolomite.
TN-B	Valley and Ridge, 100% pasture, cherty silt loam developed over dolomite, deep internal drainage appears rapid.
TN-C	Central Basin, mixed row and hay crops, pasture, silt loam topsoils with phosphatic subsoils extending to bedrock.
TN-D	Gulf Coastal Plain, mixed row crops and woods, silt loam topsoils over deep slowly pervious subsoils.
TN-E	Cumberland Plateau, mostly pasture, 3 to 5 feet sandy loam over sandstone, hydrologic characteristics significantly affected by snowmelt.
VA-A	Representative of Southern and Northern Piedmont areas, with general farms and woods, many soils associated with limestone.
VA-B	Representative of Appalachian Valley areas with mixed cover, many soils have moderate to rapid permeability, many geologic formations are stratified.
VA-C	Representative of Blue Ridge Mountain areas, in woods and general farms.

equivalent to 27% of the precipitation.

The soil of the Cumberland Plateau (TN-E) watersheds is about 3-5 feet of sandy loam over sandstone. During the winter months, the watersheds are often covered with snow much of the time. These two factors account for the very high average runoff values of 91% and 35% during the dormant and growing seasons, respectively.

The Piedmont watersheds (VA-A), which are representative of most of the VA Piedmont, yielded 36% and 13% of the runoff during the dormant and growing seasons, respectively. The Appalachian Valley watersheds

(VA-B) yielded only about 5.1% of the average annual precipitation, probably because of the moderate to rapid permeability of many of the soils. The Blue Ridge (VA-C) watersheds yielded an average of 12.3% of the average annual precipitation. This might be expected, since much of the topography is mountainous.

The data of Table II suggest that the characteristics of the watersheds of the Southern States vary widely. Table I shows generally higher water yields for the same states than Table II. This could be largely because the data of Table I were derived from streamflow data of large watersheds while the data of Table II were developed from small watersheds.

SUBSURFACE WATER

General Overview. Groundwater furnishes only a small quantity (17% or less) of the total water used in most of the Southern States; however, LA, FL, MA, and AR receive 17%, 20%, 37%, and 50%, respectively, of their water from groundwater supplies (Geraghty et al, 2). Even though the total use by many of the states is small, groundwater is important in many locations where other sources of supply are not available or less desirable.

Data from Geraghty et al (2) indicate that unconsolidated aquifers in which high yielding wells can often be developed are found in most of LA and MS as well as in much of AR, AL, SC, and NC. Consolidated aquifers associated with low to average yielding wells are found in much of FL, GA, AL, TN, and VA. Many areas of GA, NC, SC, VA, TN, KY, and AR also have poor yielding aquifers.

Recent Research. Wilson and Wiser (13) proposed that if a method for inducing faster seepage of surface runoff into the ground could be developed, then steady baseflow could be increased while flood flows would be decreased. Wilson and Wiser estimated the equivalent of 2-3 years' precipitation storage in the unsaturated soil profile (above the water table), and about the same quantity below the water table and above bedrock.

In shallow groundwater studies of the SC Coastal Plain, Wilson* determined the water table to be within 5-15 feet of the ground surface. The aquifer was often found to be 25 to 40 feet in depth. This water is frequently available from shallow wells. A 10-Foot saturated depth of aquifer would yield from 10 to 15 inches of water. This water, if not used, drains into permanent streams; but if withdrawn, it is usually replaced during the winter and spring. Thus, under such conditions, 10 to 15 inches of groundwater per year might be expected to be available without permanently depleting groundwater supplies.

Groundwater Recharge. This technique offers potential for replenishing, in many areas, our decreasing groundwater supplies. The lowering of water tables through pumping at rates exceeding the natural recharge has received most attention in the Western and Southwestern States. Groundwater recharge usually depends upon collecting surface water in recharge basins having floors with sufficiently high infiltration capacities to allow the collected water to seep into the aquifer below.

Major problems associated with groundwater recharge are the lack of availability of suitable recharge basins due to land topography, shortages of recharge water, low infiltration of recharge basin floors, concerns for groundwater quality, aquifers of limited depth and extent, and surface sediments in recharge water which may drastically reduce the infiltration capacity of recharge basin floors. Grover et al (3), in a study, reported that surface sediments in ponded recharge basins reduced the intake to 2% of that prior to the sediment depositions.

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*Personal communication with Dr. T. V. Wilson, Professor, Agricultural Engineering Department, Clemson University.

Groundwater recharge is obviously related to infiltration. Ahmed and Ligon (1) estimated field infiltration into layered sandy clay loam soils of the SC Piedmont. After four hours of continuous simulated rainfall, they found infiltration rates to vary between 0.5 and 1.0 inches per hour.

Waste water may be conserved for further use or reuse through renovation. Renovated waters may be returned to surface waters or, through groundwater recharge, introduced into groundwater aquifers. Myers (7) described a wastewater recycling research approach now being developed by Pennsylvania State University. Wastewaters are returned to forested lands by irrigation at rates sufficiently low to allow the biological and chemical environment of the surface several inches of soil receiving the wastewater to renovate the water. Under an aerobic environment, most of the plant nutrients of the wastewater are removed through utilization, and most of the harmful bacteria are neutralized. Then, depending on the infiltration capacity of the soil, the renovated wastewater seeps into the aquifer, recharging it. The water is then available for reuse through pumping from the aquifer.

RESEARCH NEEDS

Most of the water yield and supply research done in the 1960s was quantity oriented; beginning in the 1970s, water-related research has become quality oriented. Many water supply problems, however, still remain unsolved. The following research problems, not necessarily listed in order of priorities, appear deserving of further study:

1. Improve watershed management techniques for optimum utilization of soil and water resources consistent with desired water quality standards.
2. Determine effects of watershed modification and channelization on the hydrology of the watershed, downstream areas, and wetlands.
3. Improve knowledge about the interrelationships among components of the hydrologic cycle to make possible the development of more precise models for the solution of hydrologic problems.
4. Develop improved techniques for predicting hydrologic frequencies.
5. Develop better techniques for increasing the natural and artificial recharge rates of groundwater aquifers.
6. Investigate techniques for preventing the encroachment of salt and brackish water into fresh water aquifers.
7. Determine soil-plant-water-atmosphere relationships which affect efficient water use.
8. Evaluate water use demands in the Southern States in situations of conflicting needs.

CONCLUSIONS

Factors affecting the availability and dependability of water supplies from surface and subsurface sources are varied and diffuse. A variety of hydrologic models characterizing water yield have been developed, but many of these models make accurate predictions only for watersheds with the same hydrologic characteristics as those on which the models were developed. The need for further refinement of such models to take into account parameter variations with changes in geographic location and season still exists.

However, much progress on the management and prediction of the availability of all types of water supplies has been made in the past two decades. Hydrologists, reservoir managers, and directors of municipal water supply facilities are now better able to predict and provide continuous and adequate water service.

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Chapter 4

MULTI–PURPOSE USE OF WATER IN THE SOUTHEAST

T.V. Wilson

ABSTRACT

A general assessment of water supply found in 15 States of the Southeastern quadrant of the U. S. is given. Average water withdrawals by states for various uses is compared with water available, showing that on the average water in the Southeast is available for all needs, although some areas are approaching critical conditions. Likewise, ample water supplies for foreseeable future needs are predicted.

MULTI–PURPOSE USE OF WATER IN THE SOUTHEAST

T.V. Wilson [1]

Water is different from most other natural resources. It can be used for heating or cooling, transporting suspended or floating materials, and in many other ways without changing its basic characteristics. By comparison, look at petroleum products - one use-cycle changes its chemistry, making it a pollutant in the atmosphere, and rendering it unusable for foreseeable future generations. Most other natural resources fall into the same category with petroleum products - some, such as forest products, are renewable within a much shorter cycle than petroleum, coal, and the many elements, but most differ from water since they are not reusable time after time without altering their basic properties. Water falling on the mountains at Coweeta Hydrologic Laboratories in Western North Carolina can be used by many industries, many municipalities, transport many tons of pollution before going into the Gulf of Mexico to be evaporated into the atmosphere and possibly fall on the same mountains again. So water, generally speaking, when lost at a specific time and place is not lost forever. It is still around and still in a usable form, however polluted it may be.

Clawson (2) when referring to the increased needs for water to handle increasing industrial expansion and increasing population requirements explained that water is used lavishly because it is so cheap. The best grade of potable water can be delivered to a home or office or factory for 15 cents a ton, or less. What other raw material can be obtained so cheaply?

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[1] Professor of Agricultural Engineering, Clemson University, Clemson, S. C.

Are the availability of water and gasoline compatible? Examination of the situation tells us that they are compatible to some extent at least. In the late summer of 1973 the country was led to believe that a gasoline shortage existed, but that it was only temporary as a result of heavy usage during the vacation period in combination with inadequate refinery facilities. The situation did ease up in the fall but again before the end of 1973, the country was warned about pending fuel shortages, for reasons too numerous to detail here. However, one important factor in the fall shortage was that of "rate of daily consumption". Officials are now deliberating about whether to start rationing fuel, but in the meantime are permitting steady rises in the costs of fuel. If costs go high enough, people will automatically cut back on use and rationing will not be necessary. If left uncontrolled, the law of supply and demand will work out a balance between fuel available and money available for its purchase. Undoubtedly, many low income people would be hit the hardest in this type of situation, and the major oil companies would benefit enormously. Does water fall into the same category? Charges are not made for oil or water, per se. They are natural resources, and belong to everybody (or nobody) in this country. When water is taken from a stream or from groundwater storage, one must comply with the laws governing its removal, but there is no charge for it. The charge comes in processing, storing, pumping, and piping it to its point of use. Suppose the government made a charge for water - then it would cost 15 cents per ton plus the surcharge. The higher cost to the customer would cause him to start thinking about ways of reducing his needs for water - the higher the cost, the more serious he would be about cutting down on his usage. Clawson (2) pointed out that scarcity of water is a state of mind; it exists largely because we price it so low.

All this is to say that if water ever becomes a scarce item in the Southeast, one way to remedy the situation is to increase the price, as unpopular as the thought might be. Today the Western part of the United States would be much less developed if Uncle Sam had not subsidized large water development projects in past years. The National Water Commission is proposing some major changes in this area. The following is quoted from an editorial in the Irrigation Journal, September-October, 1973, page 10: "A major overhaul of U. S. water policies and programs is recommended in the final report of the National Water Commission. The 570 page report contains 232 specific recommendations for improving future water resources policies to adapt them to future needs. The Commission's recommendations on cost-sharing include the stipulation that identifiable beneficiaries of water programs and projects be required to pay the full costs of developments which give them economic benefits. Adoption of these recommendations would make a drastic change in programs such as irrigation, flood control, and inland navigation where the Federal taxpayer has been bearing from 50 to 100 per cent of the cost." If adopted, these recommendations can have far-reaching effect in our total water picture in the U. S. The brunt of it would be felt in the area of irrigation in western states, although the Southeast might be hit to some extent by the inland navigation and flood control phases.

To get a little closer to the assigned subject, there are probably several ways in which the subject could be handled, but in all cases it is apparent that numerous numbers and large numbers will be necessary. In this paper simplicity will be attempted without loss of accuracy or meaning.

The source of all fresh water in the Southeast is precipitation. The average annual precipitation in the Southeastern quadrant of the U. S. ranges from a low of approximately 35 inches in northern Virginia to more than 80 inches in the mountains near the three-state junction of N. C., S. C., and Georgia.[2] An average of about 67 per cent of the precipitation goes back to the atmosphere as evaporation and transpiration - one factor over which man has very little influence at the present time. The annual potential evapotranspiration for the Southeastern quadrant of the country ranges from a low of about 27 inches in the Smoky Mountains to a maximum of approximately 50 near the southern tip of Florida.

Any discussion regarding the use of water refers to the use of water which is not lost directly back into the atmosphere in the form of evapotranspiration (ET)-roughly 33 per cent of the annual precipitation in the Southeast, or an average of approximately 15 inches of water.

It is pointed out by Geraghty, et al. (3) that if only one per cent of the water lost to ET could be converted to streamflow, it would satisfy the entire metropolitan water needs of the present U. S. population. Some research has been directed toward reducing ET losses under certain conditions. Perhaps this is an area where research efforts will pay off in future years, but nothing of a real promising nature is available to date.

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[2] Figures and tables in this paper draw heavily from the Water Atlas of the United States, published by The Water Information Center, Port Washington, N. Y. 1973.

Other possibilities for stabilizing streamflow exist, and are touched on in at least one other paper in this symposium - one is that of possibly reducing peak surface runoff with its resultant wastage, and storing it in groundwater storage to later supplement baseflow during times of low flow. Such action would not necessarily increase total streamflow but it would serve as a stabilizing influence by reducing peaks and adding to low-flows.

One way of showing precipitation, potential ET, runoff, and the proportion of runoff to precipitation is in tabular form. Table 1 shows these relationships for 15 Southeastern States and the District of Columbia, giving in each case an average for the state. No claim is made that these are exact figures, but they are somewhere near the actual average amounts. Examination of the table shows that runoff shown does not equal precipitation minus potential ET - this is correctly portrayed. Very seldom if ever does the Southeast go through a season when some drought conditions or reduced ET rates resulting from plant water stressing does not take place. That is, seldom if ever will actual ET equal potential ET without supplementing rainfall with irrigation during periods of poor rainfall distribution. The last column of Table 1 shows annual runoff as a percentage of annual precipitation. In the states listed the variation ranges from a low of 18.9 (Florida) to a high of 41.8 (West Virginia). The arithmatic average for the Southeast is 1/3 as stated earlier in this paper.

The same information is given in chart form in Figure 1 for each of the 15 States and the District of Columbia. For Texas, the fact that ET

Table 1. Average annual precipitation, evapotranspiration, runoff, and ratio of runoff to precipitation in 15 Southeastern States and D. C. (1970 figures; source, Water Atlas of the U. S.)

	Rainfall (inches)	Potential ET (inches)	Runoff (inches)	Runoff/Rainfall (per cent)
Alabama	53	35	22	41.5
Arkansas	48	35	18	37.5
Delaware	42	30	15	35.7
Florida	53	45	10	18.9
Georgia	50	37	16	32.0
Kentucky	45	31	17	37.7
Louisiana	55	41	17	30.9
Maryland	42	30	15	35.7
Mississippi	53	38	18	34.0
North Carolina	50	34	20	40.0
South Carolina	48	36	16	33.3
Tennessee	50	33	20	40.0
Texas	31	42	2	6.4
Virginia	43	31	15	34.9
West Virginia	43	29	18	41.8
D. C.	42	30	15	35.7

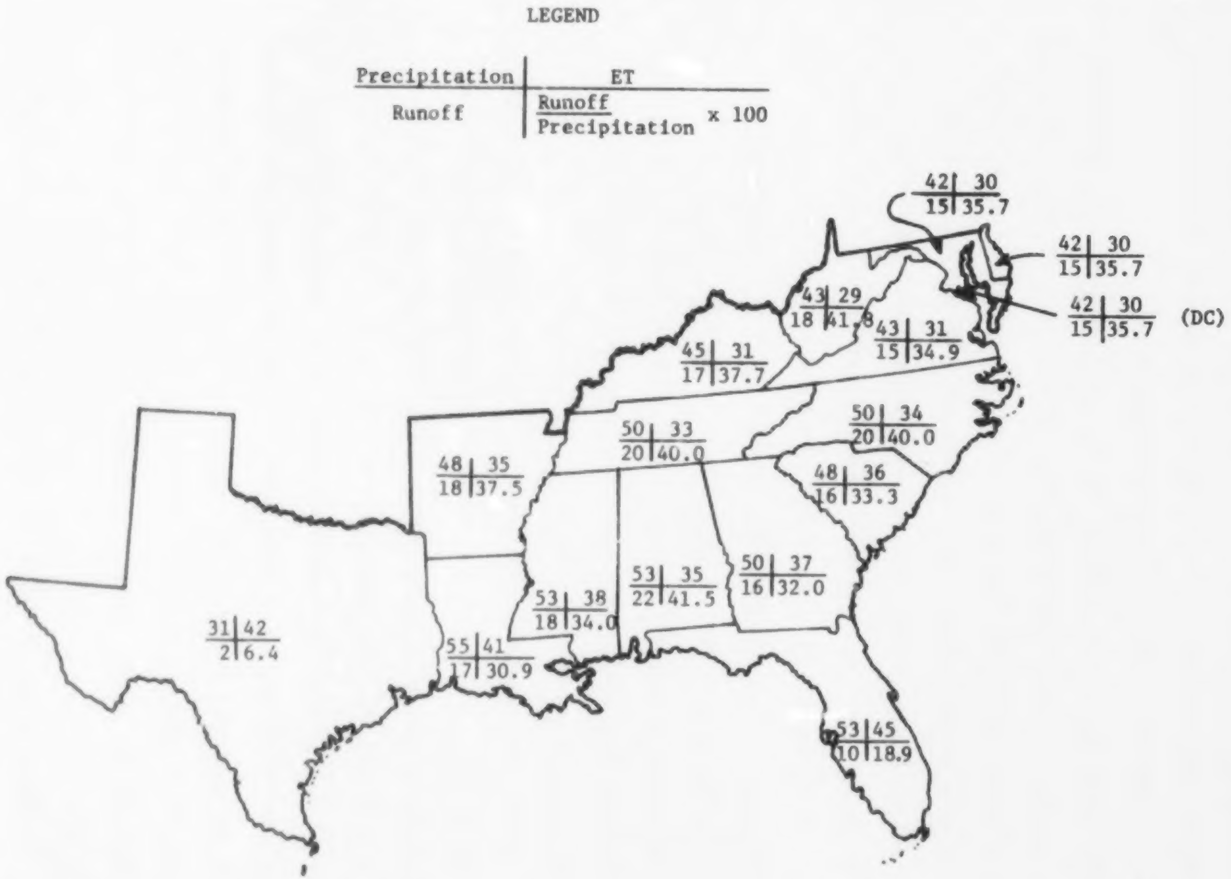
LEGEND
Precipitation | ET
Runoff | Runoff / Precipitation x 100
42 | 30
15 | 35.7
42 | 30
15 | 35.7
42 | 30
15 | 35.7 (DC)
43 | 29
18 | 41.8
43 | 31
15 | 34.9
45 | 31
17 | 37.7
50 | 34
20 | 40.0
50 | 33
20 | 40.0
48 | 35
18 | 37.5
48 | 36
16 | 33.3
31 | 42
2 | 6.4
53 | 38
18 | 34.0
53 | 35
22 | 41.5
50 | 37
16 | 32.0
55 | 41
17 | 30.9
53 | 45
10 | 18.9

Figure 1. Average annual precipitation, ET, runoff, and percentage of runoff to precipitation.

is greater than precipitation combined with a much lower runoff percentage, makes it stand out differently from the other states.

For the same group of states, Table 2 shows average daily precipitation, runoff, and water withdrawals for various uses, all expressed in units of inches of water. For example, daily runoff for Alabama is the equivalent of water spread 0.06027 inches deep over the entire state. Likewise, daily precipitation for Alabama is the equivalent of 0.145 inches rain per day over the entire state. Stating daily water withdrawals in terms of inches makes some numbers very small but it does have the advantage of direct comparison of water withdrawn for various uses, and a comparison with what is available as streamflow.

Texas was included in these tables to show the relative difference in water use in a state with relatively less precipitation, higher ET, and more irrigation.

Table 3 was developed from Table 2. It gives water withdrawn daily for various uses as a percentage of daily runoff. Although the percentages given are in terms of daily runoff, it is not intended to convey the notion that all of the water comes from runoff. Groundwater is used in every state. The approximate percentage of groundwater usage by states is also shown in Table 3, ranging from only one per cent in West Virginia to 50 per cent in Arkansas. The Southeast is fortunate to have abundant groundwater supplies which have not been utilized to their full potential to date (except in some isolated cases where overpumping has caused problems).

In Tables 2 and 3 no attempt has been made to distinguish between water consumed and water not consumed. Irrigation, for example, is a

Table 2. Average daily precipitation, runoff, and water withdrawal for selected uses in 15 Southeastern States and the District of Columbia (in inches). (1970 figures; Source, Water Atlas of the U. S.)

			Water Withdrawal						
	Precipitation	Runoff	Public water supplies	Industry	Rural use	Irrig.	Air cond.	Total excluding hydro-elect.	For hydro elect. power
Ala.	.145	.06027	.00053	.00685	.00010	.00002	.00003	.00753	.01460
Ark.	.131	.04932	.00019	.00164	.00009	.00143	.00003	.00329	.02742
Del.	.115	.04110	.00223	.03224	.00038	.00009	.00006	.03518	0
Fla.	.145	.02740	.00092	.01260	.00021	.00231	.00005	.01575	.01155
Ga.	.137	.04384	.00053	.00451	.00010	.00005	.00002	.00520	.04414
Ky.	.123	.04658	.00026	.00602	.00013	.00001	.00005	.00645	.11325
La.	.150	.04658	.00048	.00888	.00011	.00203	.00002	.01154	0
Md.	.115	.04110	.00243	.02665	.00033	.00004	.00022	.03013	.13327
Miss.	.145	.04932	.00024	.00186	.00008	.00046	.00002	.00261	0
NC	.137	.05479	.00054	.00615	.00019	.00010	.00002	.00697	.10400
SC	.131	.04384	.00057	.00567	.00010	.00005	.00002	.00642	.07744
Tenn.	.137	.05479	.00055	.00815	.00010	.00001	.00007	.00884	.17962
Tex.	.085	.00548	.00031	.00329	.00005	.00220	.00004	.00610	.00204
Va.	.118	.04110	.00056	.00730	.00014	.00005	.00002	.00787	.02289
W.Va.	.118	.04932	.00043	.013[illegible]	.00006	0	0	.01391	.05995
DC	.115	.04110	.14865	1.02194	0	0	.00641	1.20774	.00557

Table 3. Percentage of daily runoff withdrawn for various uses in 15 Southeastern States and the District of Columbia - computed from Table 2.

	Public water supply	Industry	Rural use	Irrig.	Air cond.	Total exclud. hydro-elect.	Hydro-elect. power gen.	Ground-water*
Ala.	0.88	11.37	0.17	0.03	0.05	12.49	24.22	4.0
Ark.	0.39	3.33	0.18	2.90	0.06	6.67	55.60	50.0
Del.	5.43	78.44	0.92	0.22	0.15	85.35	0	6.0
Fla.	3.36	45.99	0.77	8.43	0.18	57.48	42.15	20.0
Ga.	1.21	10.29	0.23	0.11	0.05	11.86	100.68	12.0
Ky.	0.56	12.92	0.28	0.02	0.11	13.85	243.13	4.0
La.	1.03	19.06	0.24	4.36	0.04	24.77	0	17.0
Md.	6.05	66.30	0.82	0.10	0.55	74.96	331.55	3.0
Miss.	0.49	3.77	0.16	0.93	0.04	5.29	0	37.0
NC	0.99	11.22	0.35	0.18	0.04	12.72	189.82	7.0
SC	1.30	12.93	0.23	0.11	0.05	14.64	176.64	5.0
Tenn.	1.00	14.87	0.18	0.02	0.13	16.13	327.83	5.0
Tex.	5.66	60.04	0.91	40.15	0.73	111.31	37.23	34.0
Va.	1.36	17.76	0.34	0.12	0.05	19.15	55.69	5.0
W.Va.	0.87	27.23	0.12	0	0	28.20	121.55	1.0
DC	361.68	2486.00	0	0	15.60	2939.00	13.55	0

* This column gives the per cent of total withdrawals, excluding hydro-electric power generation, which comes from wells rather than from surface supplies.

consumptive use. Part of the public water supply is a consumptive use, and part of industry water is a consumptive use, but most of the total water use in the Southeast is a non-consumptive use. Probably less than 10 per cent of the total water used is consumed. Power generation, whether it be hydro, steam plant, or nuclear plant is mostly a non-consumptive use. However, future uses of nuclear plants involving the use of cooling towers for heat dissipation will add to the consumptive use of water.

Some of the same information given in Table 3 has been put into graphical form on Figure 2. This figure shows total daily withdrawal by states exclusive of hydro-electric power generation, withdrawals for hydro-electric power generation, and the use of groundwater as a percentage of total water withdrawal.

The District of Columbia is included as a matter in interest. If the city of Washington had been included with Virginia or Maryland, it would not have distorted the figures nearly so much, but standing alone it does really stand out. According to Braeckman (1) the peak rate of withdrawal from the Potomac River has exceeded the minimum rate of flow. This is one of the few critical areas of water supply in the Southeast.

The tables and charts presented do not include recreation as a water use. It has been and will continue to be, perhaps on a larger scale, a very important use of water - for fishing, boating, skiing, swimming, etc. Every state in the Southeast has many fresh water lakes which are used for recreation. For example, Florida alone has over 4400 square miles of fresh water lake surface (about 8 per cent of the area in Florida). Lakes and other wetlands are also important to the water economy by

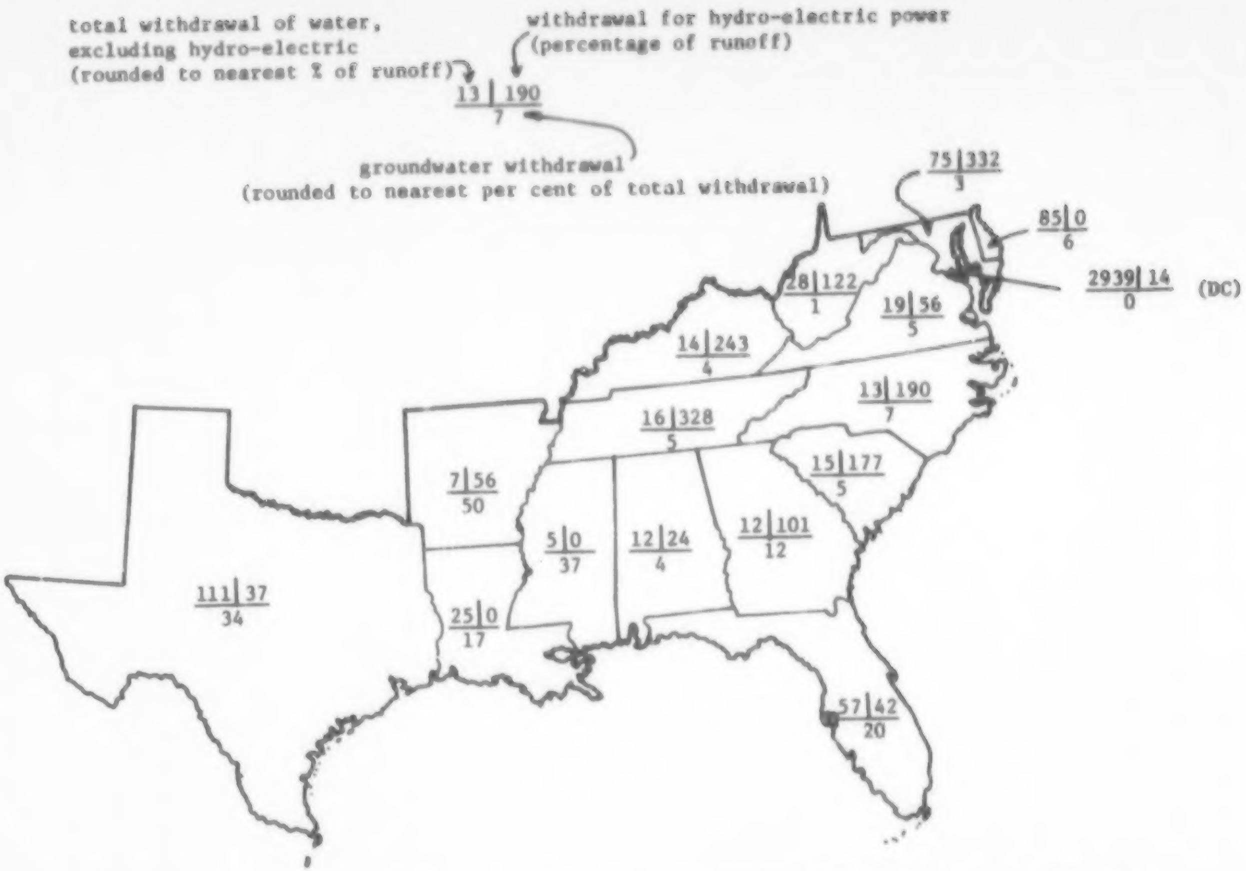
total withdrawal of water,
excluding hydro-electric
(rounded to nearest % of runoff)
withdrawal for hydro-electric power
(percentage of runoff)
13 | 190
7
groundwater withdrawal
(rounded to nearest per cent of total withdrawal)
75|332
3
85|0
6
2939|14
0
(DC)
28|122
1
19|56
5
14|243
4
13|190
7
16|328
5
15|177
5
7|56
50
5|0
37
12|24
4
12|101
12
111|37
34
25|0
17
57|42
20

Figure 2. Estimated water withdrawal for hydro-electric power generation, for all other uses, and

serving as groundwater recharge areas.

The outlook for adequate water supplies to meet future demands in the Southeast is good. There is and will be ample water for any reasonable use. Pollution will have to be controlled so that water can be used and re-used many times. The largest consumptive use of water is irrigation. Irrigated acreages will probably increase in the Southeast, but not to the point where water shortages are anticipated. Practically all other uses will increase, too, with an increasing population and rapidly increasing industrial expansion in the Southeast. Even so, the outlook is good. Perhaps the projected water demand and supply shown by Geraghy, et al. (3) is the best estimate available. It shows for the South Atlantic-Gulf States (N. C., S. C., Ga., Fla., Ala., parts of Miss. and Va.) that by the year 2000 there will be 197 billion gallons of runoff per day, and a total use of 87 billion gallons per day, of which 6 billion gallons per day are consumptively used. That is approximately 44 per cent of runoff used, and about 3 per cent consumed.

Average figures can be misleading, whether discussing the present situation or future expected conditions. Average conditions indicate that the Southeast is currently in excellent shape when comparing withdrawals with water available. Generally, this is true, but the situation is much nearer a critical level in some places than in others (Washington, D. C., for example). More precautions will be necessary in the future - even though predictions for the future show that water supplies will be more than adequate, the tendency for supplies to become critical in rapidly growing population and/or industrial centers will accelerate unless adequate plans are made well in advance of needs.

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Chapter 5

RURAL–URBAN DEVELOPMENT AND SEDIMENTATION

Robert W. Oertel

ABSTRACT

Development of rural and urban land, the process of erosion, and the production of sediment are intimately related. Changes in any one of them ultimately affect each of the others.

Soil erosion and sediment are major factors in the overall deterioration of our natural resources and our total environment. Sediment pollution is a much more extensive and expensive problem than is generally recognized. The pollution caused by sediment is increasing steadily as development, redevelopment, and construction activities increase in areas undergoing rapid urban expansion.

Effective techniques of predicting and controlling erosion and sediment are available and in widespread use on lands used for agriculture. Many of the practices used successfully on rural land are being adapted for use in controlling erosion in urban areas. However, more research is needed to predict and control urban erosion and sedimentation.

Slowly, but surely, soil erosion is being declared illegal in this country as more and more counties and states enact erosion and sediment control ordinances and laws. The voluntary adoption of soil and water conservation programs over the past four decades by over two million rural land owners and users in the United States has been highly effective and successful. This is now being supplemented by compulsory and restrictive legislation aimed at mushrooming erosion and sediment problems in developing urban areas. It will ultimately affect all land users in urban and rural areas.

INTRODUCTION

Land development is a major element in the history of the United States. It includes every action taken to transform nature, as found on this continent by Europeans, into uses for the service of man.

Development has always been a driving force of the American spirit. Early in the history of our country, pioneers cleared forests and began developing the land for the production of crops. The harvested trees were converted into lumber for houses, and businesses, and even for the building of railroad tracks.

As the pioneers pushed through the forests of the eastern region of our country, they viewed the vast prairie lands of the midwest. Tall native grasses growing on fertile prairie soils produced a tough hard-to-handle prairie sod. The invention of the "sod-buster" plow with its curved iron moldboard enabled those early settlers to subdue the prairie and put it to their own use.

In a relatively short time land over the entire nation was being used by man to fill his many needs. The natural ecosystems of most lands were substantially altered as efforts were expended to produce the raw materials for life.(1)

Development soon began to leave its imprint on the land forcing increasingly difficult management problems upon landowners and users. One of these was the process of land deterioriation called erosion and its inevitable partner, sedimentation. Thus there is a direct relationship between land development, erosion, and sedimentation. I will deal with this relationship and will offer an approach to the solution of the sediment problems particularly in areas undergoing rapid development.

Immediately following my presentation, Mr. Dornbusch will discuss solutions to erosion and sedimentation problems in rural areas.

DESCRIPTION OF THE PROBLEM

Sedimentation involves the processes by which mineral or organic matter is detached, transported or deposited by moving water, wind or gravity. The detachment process is called erosion and the detached particles being transported or deposited are called sediment.

Raindrops falling on bare and unprotected soil tear the tiny clumps of particles apart and bounce many of them into the air. On sloping terrain most of these fall to the ground slightly down slope from their original location. When rain falls faster than it can soak into the soil, a sheet of water forms and moves down slope carrying detached soil particles with it. As the runoff water on unprotected soils increases in volume and velocity, the erosion process intensifies and the sediment load increases.

Important factors influencing the amount of erosion include the use and management of the land, soil erodibility, land slope, slope length, erosion control practices and rainfall.(2) Researchers and soil scientists have combined these factors into an equation to predict soil erosion for land being used for agricultural purposes.(3) This erosion prediction concept is used extensively by Soil Conservation Service personnel and others in helping landowners devise erosion controlling cropping systems.

There is a staggering amount of sediment produced each year in our nation. The President's Task Force on the Quality of the Environment reported in 1967 that soil sediment from erosion accounts for the greatest part of the suspended material in the nation's rivers. It has been estimated that 4 billion cubic yards of sediment each year moves into our streams, lakes, reservoirs, estuaries, and other water bodies.(4)

About one-half of the sediment produced by erosion is attributed to agricultural endeavors. (5) The largest single contributor of the remaining 50 percent is streambank erosion. This erosion is destroying land adjacent to stream channels valued at $11 million annually and moving about 500 million tons of sediment into the streams each year.(6)

More than 56 million tons of sediment comes from unprotected roadsides and backslopes.(6) Research near Cartersville, Georgia, showed that up to 400 tons of soil per acre per year, or the equivalent of a three-inch deep layer, can be washed from unprotected roadbanks.(7)

A very sizeable amount of sediment can be produced when land use changes are made. Each year more than a million acres of land in the United States is changed from agriculture to such uses as sites for new homes, shopping centers, businesses, airports, and highways.

Many of these changes are made by people with little understanding of the detrimental effects on the land or on the total environment. In many cases, their actions create new and highly complicated environmental problems as accelerated soil erosion and sediment production, flooding, high water levels, and the deterioration of the visual qualities of the areas concerned.

Sediment yield from these areas undergoing land use change is about 10 times greater than on land in cultivated row crops, 200 times greater than on land in pasture and 2,000 times greater than on land in timber. (6)

EFFECTS OF SEDIMENT

Sediment is an economic liability of staggering proportions. In 1966, the total annual damage from sediment in streams of the United States not including loss of agricultural productivity of farm land lost to erosion, was estimated to be $262 million.(9) This included deposition of flood plains, $50 million; storage space destroyed in reservoirs, $50 million; dredging sediment from inland navigation channels and harbors, $83 million; removal of excess turbidity from public water supplies, $14 million; removal of sediments from drainage ditches and irrigation canals, $34 million; and other damages including sediment removal, cleaning and added maintenance, $31 million.

Due to rising prices and other factors, the most recent estimate of annual sediment damages is now more than $500 million.

But in addition to the physical effects of sediment, there is now increasing attention being given to its role as a carrier of plant nutrients, pesticides, disease organisms, and toxic elements such as lead, mercury, cadmium, nickel, and arsenic.(10) Plant nutrients, particularly phosphorus, potassium and certain trace elements, attach themselves to the colloidal soil particles and move with the sediment. The only apparent effective approach to stopping the movement of these elements in the sediment is to control erosion and prevent the movement of soil from its original site.

Sediment, when viewed from almost any angle, is undesirable and costly. It is a direct result of the erosion of unprotected land no matter where it is located. It follows that the reduction in sediment production is dependent upon the effectiveness of the control of erosion. Since development often creates disturbance of the land, accelerated erosion and sedimentation are interdependent and must be considered together.

NATION-WIDE SOIL AND WATER CONSERVATION PROGRAM TACKLES THE PROBLEM

In 1935, the Soil Conservation Service was created by the Congress as an agency within the U. S. Department of Agriculture. The SCS was given the responsibility of helping landowners make the best use of their land and apply needed conservation practices. Chief among the problems was the control of erosion and the prevention of sediment.

In 1937, the Georgia Legislature enacted a Soil Conservation Districts Law making it possible for landowners to organize into Soil Conservation Districts throughout the state. Georgia farmers were quick to take advantage of the law and organized into 27 districts for the purpose of developing and guiding a long-range program for combating soil erosion and improving the use and management of soil and water resources.

Since 1938, landowners in the area, and all over Georgia, have cooperated with their conservation districts. More than 108,000 of these landowners with the assistance of the Soil Conservation Service and other agencies have accomplished what we might call a "conservation miracle" over the past 3-1/2 decades. They are environmentalists in the best sense--real doers--not just idle talkers.

The effectiveness of this program in reducing sediment production can be vividly illustrated by a siltation study at Lake Jackson (1935-1967) on the Alcovy River near Jackson, Georgia.(11) Researchers made their first sampling in 1935 prior to the establishment of the Upper Ocmulgee River Soil and Water Conservation District. They found that 106.7 acre feet of sediment was being deposited annually in the lake by the Alcovy River.

In 1967, after 29 years of conservation assistance to landowners by the Conservation District and the Soil Conservation Service, the researchers found that sediment deposition by the Alcovy River had been cut by 73 percent to a total of only 29 acre feet per year.

The effectiveness of the soil conservation program in decreasing turbidity of stream flow is illustrated by the Oconee River in northeast Georgia. In 1939, one year after the organization of the Oconee River Soil and Water Conservation District, the average turbidity rate (suspended sediment load) at Milledgeville on the Oconee River was 315 parts per million.(12) Thirty years later in 1969, the average turbidity rate at Athens upstream from Lake Sinclair at Milledgeville was only 40 parts per million.(13)

CONTROLLING URBAN AND SUBURBAN SEDIMENT

While efforts to control erosion and sediment in rural areas have been highly effective, these same problems in urban areas undergoing rapid development are more complex and involve the activities of many organizations and levels of government.

Erosion and sediment in these areas inflict heavy damages on local governments, businesses, and citizens. Local officials in many cases have failed to meet these problems head on, hoping they will either improve or disappear.

Suggested guidelines and standards for erosion and sediment control programs are now being made available to public officials. One of the best of these was developed by the National Association of Conservation Districts with the technical assistance of the Soil Conservation Service.(14) These guidelines and standards provide information for implementing the technical phases of erosion and sediment control programs such as Sections 3 and 4 of the Model State Act for Soil Erosion and Sediment Control. This act was developed by the Committee on Suggested State Legislation, Council of State Governments in 1972.

Effective action to meet the challenges of erosion and sediment production connected with changing land use in any urbanizing area, consists of four major steps.

1. Local governmental bodies must adopt a stated policy of erosion and sediment control.
2. Soil and water conservation districts must take aggressive leadership in advising local governments on the capabilities and limitations of land.
3. Effective erosion and sediment control rules and other ordinances related to natural resources must be adopted.
4. A full-scale information effort must be carried on.

I will discuss these by using the Atlanta, Georgia metropolitan area as a case study. Progressive action is underway in this rapidly developing metro area as it tries to solve its many erosion and sediment problems.

1. A stated policy of erosion and sediment control

"Easy to say, hard to do" might describe this step. How easy it is for folks to say, "Isn't that erosion awful! Somebody ought to do something about it." That's about as far as it goes unless or until the damages hit hard, close to home.

Around Atlanta, the erosion problem was noted by soil and water conservation districts and SCS people for many years. Some corrective action was taken by individual landowners cooperating with the districts, but the overall problems kept increasing in severity and extent. Sediment from construction sites around the city edges occasionally filled downstream lakes in suburban areas. Lawsuits and threats of lawsuits by irate landowners suffering sediment damage became commonplace.

County governments decided it was time to quit talking and to take positive action. Gwinnett County officials were the first to act when they took a solid position for controlling erosion. They came by this decision as a culmination of years of cooperative work with the local soil and water conservation district supervisors and respresentatives of local USDA agencies--SCS, Extension Service, Farmers House Administration, and others.

As active partners in the Gwinett County Resource Conservation and Development Project, the county commissioners had a good understanding of the problems and possible solutions. Their public affirmation against the erosion and sediment problems set the stage for ordinances that followed later.

2. Aggressive leadership of Conservation District Boards

Under Georgia law, soil and water conservation districts have legal responsibilities for long-range soil and water conservation programs covering all land in Georgia. Until a few years ago, their major attention focused on rural agricultural areas.

However, during the past decade there has been a gradual widening of their perspective to include soil and water related problems in metro areas. This was particularly true of the Atlanta District, which includes three metro counties and the City of Atlanta.

Supervisors of the Atlanta District include men with urban backgrounds, sensitive to the needs, actions, and reactions of urban dwellers. A recently appointed supervisor, Jim Terry, is a representative of a land developing and contracting firm in the Atlanta metro area. Jim's intimate knowledge of the problems of contractors and realtors as they develop land for nonagricultural purposes is an invaluable addition to the Atlanta Soil and Water Conservation District Board.

The Board of Supervisors over the past five years has taken specific steps to alert governmental and civic leaders to the erosion and sediment problems and to suggest corrective action. The specific steps included a dinner and seminar for members of the Georgia General Assembly from the Atlanta metro area, a day-long introductory soil erosion and sediment control seminar at Georgia Institute of Technology two years ago, and a luncheon seminar on the same subject last year in Decatur. Each of the latter two seminars was attended by about 150 officials and community leaders.

Last year the State Soil and Water Conservation Committee sponsored a Georgia Governors Conference on Sediment Control. This was attended by conservation leaders, members of the Georgia General Assembly and other governmental officials.

One of the more important leadership functions has been the day-to-day contacts of individual members of the Board with influential governmental decision makers and leaders. With their keen understanding of the problems, a dedicated sense of soil and water stewardship, and a pride in their individual communities within the sprawling metro complex, they are powerful forces for progressive action against soil erosion and sediment problems.

Conservation districts are logical leaders in any concerted effort to control these problems. But to be most effective, they must exert their leadership in a positive and dynamic manner.

3. Adoption of Effective Rules and Ordinances

A unique feature of the conservation miracle wrought by millions of landowners throughout America over the past four decades is that it was all done voluntarily. Once these poeple understood that good land use and conservation measures were sensible and economical, they responded by using the technical and financial help of the Soil Conservation Service and other Federal and State agencies. Sometimes it was a slow process--but it worked.

Today, however, there is increasing need for a different approach to the problems of erosion and sediment control in areas undergoing rapid development. Land use changes are being made so rapidly by so many people who have little or no concern for the land or resulting environmental damages that more direct restrictions seem to be a better solution than voluntary action.

The Gwinnett County government adopted a soil erosion and sediment control ordinance two years ago--the first county in Georgia to do so and one of the very few in the Nation. It required grading permits for land-disturbing operations connected with nonagricultural development. A soil erosion and sediment control plan must be presented and approved for technical adequacy before permits are issued.

Although a few people had their fingers crossed and questioned possible public reaction, acceptance by land developers and the public has been surprisingly good. It is a major step in preventing new and aggravating sediment problems.

Several other metro area county governments have since adopted similar rules and ordinances. The latest, Clayton County, adopted theirs November 20, 1973. In a short time the entire metro area is expected to have soil erosion and sediment control ordinances.

To be effective, such ordinances must be specific and include or refer to standards and specifications for erosion and sediment control. In Gwinnett County, the Soil Conservation Service developed and published a technical guide entitled "Manual of Standards and Specifications for the Control of Erosion and Sediment in Areas Undergoing Urban Development."(16)

This technical guide was made available to all county governments, developers, and others interested in the problems of urban erosion and sediment control. Its information has since been used by all counties adopting such ordinances. Needless to say, demand for these manuals has been heavy. An interesting, and significant development connected with these standards and specifications concerns the Georgia Land Development Association. This recently organized association of land developers adopted a code of ethics including the major operating principles, criteria, and details of the manual developed by SCS. The organization considers the standards and specifications of erosion and sediment control an essential element in their goal of high standards for land developers.

Adoption of these ordinances necessitates that county or city government have personnel with background and training in the science of erosion and sediment control. Taking advantage of the Intergovernmental Personnel Act (IPA), a total of four SCS men are now working with county governments in the Atlanta area. During a 2-year period, these men will help with the operations of the erosion and sediment control ordinances and train other county employees. At the end of this time, these men are expected to return to SCS having had an invaluable experience in governmental operations.

Although the counties in the metro Atlanta area are adopting their own county-wide erosion and sediment control ordinances, the Georgia

General Assembly is now considering H. B. 1070 to accomplish a state-wide comprehensive soil erosion and sediment control program. Eight states, Iowa, Michigan, Ohio, Pennsylvania, Maryland, Virginia, North Carolina, and South Carolina, have already enacted state-wide legislation and eight more have introduced legislation. Thus, it is clear that sentiment for mandatory erosion and sediment control legislation is becoming more widespread.

4. Continuing Information Program

Just as a modern auto will not run long without oil as a lubricant, neither will an erosion and sediment control program in an urban area be successful unless it is lubricated by a coordinated and effective information effort. It enables all the elements to function properly with little friction.

The public, if they know the "what" and the "why" of the program will support well-conceived and sensible erosion and sediment control ordinances.

The program must begin early and not stop. It must show the public what the problems are and then show that the necessary rules and regulations will achieve a more attractive community, save tax dollars and make the best use of limited land and water resources.

In the Atlanta area, the information effort has many facets. Among these are:

Brochures--A simple, 3-fold illustrated leaflet helps tell the story of the Gwinnett County ordinance.

--A 16-page booklet entitled "Urban Erosion and Sediment" was printed by the Georgia State Soil and Water Conservation Committee and the Soil Conservation Service.

This easy-to-read booklet printed on slick paper with few words and pictures gives the basic steps for an effective control program.

__Public Speeches__ --Slide-illustrated talks are a basic ingredient in telling the story to such varied groups as the Home Builders Association, the Association of Building Inspectors, service clubs, ladies and garden clubs, and school groups. Frequent use is made of the film "Mud".

__News Media__ --Feature and news items by the newspapers and radio and television stations tell the story in many ways and from many viewpoints.

__Seminars__ --These are held as opportunities develop. The latest one was held February 6, in Clayton County, which is beginning to implement a recently adopted ordinance.

RURAL-URBAN DEVELOPMENT AND SEDIMENTATION

SUMMARY

Development of rural and urban land, the process of erosion, and the production of sediment are intimately related. Changes in any one of them ultimately affect each of the others.

Soil erosion and sediment are major factors in the overall deterioration of our natural resources and our total environment. Sediment pollution is a much more extensive and expensive problem than is generally recognized. The pollution caused by sediment is increasing steadily as development, redevelopment and construction activities increase in areas undergoing rapid urban expansion.

Effective techniques of predicting and controlling erosion and sediment are available and in widespread use on lands used for agriculture. Many of the practices used successfully on rural land are being adapted for use in controlling erosion in urban areas. However, more research is needed to predict and control urban erosion and sedimentation.

Slowly, but surely, soil erosion is being declared illegal in this country as more and more counties and states enact erosion and sediment control ordinances and laws. The voluntary adoption of soil and water conservation programs over the past four decades by over two million rural land owners and users in the United States has been highly effective and successful. This is now being supplemented by compulsory and restrictive legislation aimed at mushrooming erosion and sediment problems in developing urban areas. It will ultimately affect all land users in urban and rural areas.

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ABSTRACT

USING CONSERVATION SYSTEMS TO CONTROL EROSION

August J. Dornbusch, Jr. [1]

This paper describes how the Soil Conservation Service assists decision makers with their erosion problems through the Soil Conservation District.

It describes the factors which make up the soil loss equation and how each affects soil erosion. The soil loss equation is used by the conservation planner in determining which combination of a cropping management system, erosion control system, and a water management system is needed to meet the tolerable soil loss and still meet the objectives of the decision makers.

It also discusses how these decisions and alternatives are recorded in a conservation plan so to provide the decision maker with a blueprint to keep his soil erosion problems within tolerable limits.

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Chapter 6

USING CONSERVATION SYSTEMS TO CONTROL EROSION

August J. Dornbusch, Jr.

The soil erosion problem has been with us since geologic times. Thousands of severely eroded acres, sediment-clogged streams, and fence posts buried almost to their tops, attest to the accelerated erosion that has occurred in this nation since man started tilling the land and the landscape in Georgia is no exception.

Background of the Soil Conservation Service

In the early 1930's most people in the United States were not concerned about erosion. People felt that the soil was the most indestructible, immutable asset that the nation possessed. They felt that it was one of the resources that could not be exhausted; that it could not be used up. However, a man by the name of Hugh Bennett came on the scene in Washington and was extremely concerned about erosion and the way it was scarring the landscape. He was a man of great vision and a leading authority on erosion. His persistence and drive led to the creation of the Soil Conservation Service when on April 27, 1935, the 74th Congress passed PL-46. This was also the time when the winds in the Mid and Southwest had created

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Presented by August J. Dornbusch, Jr., State Conservation Engineer, U.S. Department of Agriculture, Soil Conservation Service, Athens, Georgia at the Water Resources Symposium, Fort Valley State College, Fort Valley, Georgia, February 27, 1974.

great dust bowl storms lifting such great quantities of dust into the air streams that the sun over the Capitol was blotted out.

The Soil Conservation Service was organized to provide technical assistance to a farmer on his soil and water problems and particularly on erosion problems. At that time, assistance was related to soil, plants, and engineering problems. To be able to provide effective assistance to farmers, each state passed a state soil conservation district law to provide a governmental subdivision at state level to assist the farmer with his soil erosion problems. Georgia adopted this law in 1937, and the Coosa River Soil and Water Conservation District in Georgia was the second District organized in the U.S., and the state is now covered by 27 soil and water conservation districts.

Land Having Erosion Potential

What were the conditions when the SCS started to provide assistance to the districts? The State of Georgia contains approximately 37.3 million acres of land. In the 1930's and early 1940's, approximately 10.5 million acres, or 28 percent of the land within the state, was cultivated. 1/ Much of the land was too steep for cultivation and as a result had become severely eroded. However, a dramatic land use change has taken place in the past 25 to 30 years in Georgia to convert these severely eroded cropland acres into timber and pasture lands, uses to which they are better suited, and thus reduce the erosion potential.

By 1967, the Conservation Needs Inventory for Georgia showed that the cropland acres had been reduced by approximately 4 million acres to 6,522,300 acres. However, 3,477,000 acres of the 6,522,300 acres have slopes of 2 to 8 percent and are subject to erosion. These are acres which if not properly treated have the potential for erosion in excess of limits deemed safe for sustained use. The report also indicated approximately 763,000 acres (12 percent) of this sloping cropland has received adequate treatment to meet tolerable soil loss limits leaving 2,714,000 acres still needing treatment.

In addition to cropland acres, there are many acres going into housing developments, industrial areas, roads, and other uses each year and subject to severe erosion. The number of acres undergoing development each year is small compared to the number of acres being cropped, but the amount of erosion that can take place may be as much as 25 times [2] that which occurs on sloping cropland. The five metropolitan areas of Atlanta, Macon, Columbus, Savannah, and Augusta are where most of this land use change is occurring.

The estimated 15,000 acres of existing bare road banks in Georgia are also high sediment-producing areas. [3] Urban and road land uses having erosion potential will not be discussed further in this paper. However, the following discussion and solutions to erosion applies to both of them.

Elements Which Affect Erosion

The erosion was visible and it was evident the erosion varied from place to place. What were the factors which affected it? The SCS needed to know and needed a method of predicting soil losses. Through the cooperative research ef[illegible] of the Agricultural Research Service and the Soil Conservation Service and under the leadership of Walter H. Wischmeier and Dwight D. Smith, a soil-loss equation was developed. The equation is

A = R KLSCP, where "A" is the computed soil loss per unit area, "R" is the rainfall factor, "K" is the erodibility factor, "L" is the slope length, "S" is the slope gradient factor, "C" is the crop management factor, and "P" is the erosion control practice factor. The following is a discussion of each of these items:

(1) The first element to consider is the soil itself. There are approximately 8,000 soils identified in the United States, and 250 are found here in Georgia. These soils erode at various rates, expressed by the term "erodibility." The erodibility factor "K" of a soil is a measure of the rate at which it erodes and is expressed in tons per acre. The soils in Georgia used for cropland number approximately 155 and have been placed in eight erodibility groups.

The soil properties that influence erodibility by water are those that affect the infiltration rate, permeability, and total water capacity, and those that resist the detaching dispersion, splashing, abrasion, and transporting forces of rainfall and runoff. 4/

The Soil Conservation Service has the responsibility of providing soil survey information. The objective is to get the entire state mapped and the soils information published in Soil Survey reports with appropriate interpretations. At the present time, we have published reports covering 41 counties; 19 counties have surveys complete but awaiting publication, and other counties have a varying degree of mapping completed (8 to 100 percent).

(2) The next element to be considered is length of slope: the "L" factor in the equation. The rate of soil erosion by water is very much affected by both slope length and the percent of slope. 4/ As the length of slope increases, the potential for erosion is also greater and, therefore, by means of vegetative or mechanical practices, or both, the effective slope length subject to erosion can be reduced.

(3) The percent of slope ("S" factor) varies greatly over the state. The relation of soil loss to percent of slope is influenced by density of vegetative cover and by soil particle size. Good vegetative cover is the best means of offsetting the effect percent of slope has on potential erosion.

To a great extent, the slope limits the use which can be made of the land, and the kinds of vegetative cover, conservation practices, and equipment that can be used.

(4) Bare soil exposed to the erosive forces of wind and water is subject to high potential soil losses. Vegetative cover, living or dead, will be discussed as to how it affects and

reduces soil erosion. This is the factor "C" in the equation. Vegetative cover breaks up the energy of the raindrop that can dislodge soil particles; it retards the flow of runoff; it provides a cover over the soil as the water runs over it. In fact, an established stand of close-growing grasses or small grains reduces soil losses, as compared to bare soil surfaces, from 95 to 99 percent. 4/

Also to be considered in this discussion is the effect of residue left on the surface of the ground from a harvest operation or of temporary cover that is established on the bare surface.

Four tons per acre of corn residue, or 2 tons per acre of hay or small-grain straw left on the soil surface reduces soil erosion by 98 percent. 4/ The minimum tillage or no-till systems being used by many farmers today utilize the residues to keep their soil losses to a minimum.

Asphalt emulsion applied at a rate of 1,250 gallons per acre is effective at reducing erosion by 98 percent. Other materials such as wood chips, wood cellulose fiber, fiberglass, fiber matting, and excelsior provide good protective cover, reducing soil erosion.

(5) Practices ("P" factor) which are effective in reducing erosion are contouring, contour strip-cropping, and terracing. In

general, whenever sloping soils are to be cultivated and exposed to erosive rains, the protection offered by grasses or close-growing crops in the system need to be supported by practices that slow the runoff water and reduce the effective slope length, thus reducing the amount of soil the runoff water can carry away.[4]

Contouring is a practice in which the tillage operation is performed on the contour of the land. It depends on each contour row acting as a small terrace. It is effective for moderate to low intensity rains; but ineffective for high intensity rains because of the extensive breakover of the individual contour rows. Contouring produces its maximum effect on slopes in the 3 to 7 percent range.

Contour strip-cropping is a practice in which contour strips of sod alternate with strips of row crop or small grain. Contour strip-cropping has proved to be a more effective practice than contouring alone. The strips are located on the contour, as nearly as possible, and vary in width according to the slope of the ground. For example, strip widths of 88 to 100 feet could be used on slopes of 2 to 7 percent with good results.[4]

Terracing has been an established practice in the erosion control program for many years. It is a positive means of dividing the slope of a field into segments. In addition, the slope length becomes the terrace interval and thus reduces one of the elements which affects erosion. Dividing a slope into four equal parts reduces the erosion by one-half. Dividing the same slope into six equal parts divides the soil-loss rate by 2.45. 4/

(6) Rainfall is an all important factor when discussing soil erosion. It is the "R" factor in the equation. Thirty years of measurements show that a rainfall factor used to estimate soil losses must include the cumulative effects of the many moderate-size storms, as well as the effects of the occasional very severe ones. It was also determined that the soil losses are dependent on the total kinetic energy of the storm times its maximum 30-minute intensity. 4/ This product is called Rainfall Erosion Index (EI) and reflects the combined potential of raindrop impact and the turbulence of runoff to transport dislodged soil particles from the field. 4/ It has been determined in Georgia that 50 percent of the erosion occurs during spring and summer months because this is when we receive our most intense rains.

The soil, rainfall, slope length, slope gradient, vegetative cover, and conservation practice must all be considered when estimating the soil loss expected on sloping land.

Sediment a Pollutant

Sediment is the number one agricultural pollutant in terms of volume. It is estimated to be 50 percent of the total yearly sediment production of 4 billion tons. 2/ Sediment carries with it the phosphate and other pollutants that are adsorbed or bound to the soil particles. Nitrates, however, normally are not adsorbed or bound to the soil particles and, therefore, they are generally transported in the runoff water.

Movement of pesticides or herbicides is generally associated with the intensity of runoff just after application.

Sediment has always been a great cost to society. We spend great sums of money each year removing sediment to restore the capacity of community water supply reservoirs, removing sediment from water courses to keep them navigable and provide flood protection, removing sediment from clogged road structures and ditches, removing flood sediment deposits from homes, businesses, and factories, repairing damage to fish and wildlife habitat and damage to agricultural lands. It is much cheaper to apply sound conservation measures to the land to keep the soil in place rather than to remove it as sediment later.

Planning Systems

From the very beginning, the conservation plan was and still is the tool used to help soil conservation district cooperators to make wise land use decisions and to apply sound conservation systems.

These plans are developed with the decisionmaker by a professional planner . . . the soil conservationist. The planner is responsible for helping develop a plan which through decisions and alternative solution, is technically sound, and meets the tolerable soil loss limitations.

The planner must determine the objectives of the decisionmaker and assist by suggesting sound technical alternatives that will meet the objective. The planner may discuss crop management systems, erosion control systems, water management systems, and animal waste management systems which could be used as component parts of the decisionmakers overall plan. He points out various alternatives of each of these systems and how they could be dovetailed into a plan to meet the overall objective. In many cases, firm decisions are made on all phases of a plan and then recorded. But often a decisionmaker is unable to make firm decisions on all aspects of the plan. The planner then records the decisions that have been made and also records the alternative solutions for the problems for which decisions could not be made. These alternatives should fit within the overall objectives of the decisionmaker. As he makes a decision on one of the alternatives, the planner records this decision and deletes the other alternatives listed. Thus, a continuous planning process is in effect until all decisions are made.

The objective of a conservation plan is to be acceptable and workable within the objective of the decisionmaker (landowner). It must be economically feasible. The decision and alternatives must be technically sound within established standards and specifications and must be within the tolerable soil loss.

Crop Management Systems

Cropping systems have an important part to play in the amount of potential erosion which may occur on a tract of land. The potential amount of erosion is related to the amount of cover the crop provides to the soil during the growing season and the amount of residue which covers the soil after the crop is harvested. This was discussed as one of the elements which affects erosion.

Prices of crops and crop allotments also dictate to a great extent what crops will be grown. Many times, these items are not consistent with good conservation of the soil.

In recent years, the "minimum till" or "no-till" system of producing a crop has been very effective in reducing soil erosion and still maintaining high crop yields. This system provides for planting the crop in sod and residue, thus keeping soil disturbance to a minimum, reducing trips over the land, and keeping erosion to nearly zero percent. It is one of the most effective cropping methods for keeping soil losses within tolerable limits. The reduction of equipment time reduces labor requirements and saves fuel.

Erosion Control Water Management System

When considering an erosion control system, there are a number of practices which can be considered such as: waterways, terraces, diversions, grade stabilization structures, debris basins, and vegetation. The use of any one of these practices depends to a large extent on what kind of cropping system is being planned.

For centuries, terraces have been a major weapon against erosion. They reduce the effective length of slope and complement a cropping system which by itself cannot keep soil losses within tolerable limits.

Through the 1930's and 1940's, the terrace system was primarily of the gradient type, following the contour of the land. Generally, point rows and correction areas were common between each terrace. These presented little problem during the horse-and-mule farming operation, but as tractors began dominating the farming operation, point rows and correction areas did not lend themselves to efficient operation. Therefore, mechanical farming had its effect on the terracing program. Parallel terrace systems were developed. Parallel terraces eliminated the point rows and correction areas. They were also laid out in widths to accommodate the size of the farmer's modern equipment.

A diversion is a large terrace that is individually designed to remove and divert runoff to a stable outlet. It may be used to keep runoff away from a severely eroded area, keep hill runoff from cropland, or divert clean water from an area where it could become polluted.

Vegetated waterways are used to carry runoff safely off the land. They can be natural waterways or ones designed and constructed for a specific need. They must be considered in every plan and are generally needed for all kinds of cropping systems.

Vegetated waterways are needed to provide safe and stable outlets for terraces and diversions. They are a must where runoff occurs and the concentrated water must be safely transported off the field.

Grade stabilization structures are often needed to stabilize headcutting gullies or outlets of waterways. A grade stabilization structure drops possible erosive runoff through a pipe or similar structure into a stable watercourse.

Debris basins can be used effectively to collect and store sediment which comes from eroding areas. Usually, a sediment basin should be used in conjunction with other erosion control measures designed to keep soil in its original location.

There is no substitute for good vegetative cover, and it is essential in any erosion control system. It needs to be used to the fullest.

Tile is generally thought of in connection with subsurface drains. It is also an excellent alternative for terrace outlets. A tile outlet can substitute for a grass waterway. Then no land need be allocated for a waterway. This may be important if land is expensive.

Floodwater retarding structures and channels are effective practices for reducing erosion and should be considered.

A floodwater retarding structure temporarily stores possible floodwater and meters it out in quantities that keep flood damages to a minimum below the structure. It is desirable to design sediment storage into the structure for its life expectancy to help reduce sediment damage downstream. These structures are effective in protecting bottomlands from damages caused by hill runoff.

Stream channels are the veins to carry the surface runoff to the ocean. They are also the transportation system for sediment. The Mississippi River is estimated to carry 500 million tons of sediment into the Gulf of Mexico each year. 2/ A channel must be considered as part of a water management system; however, it should be the last item to be used in reducing flooding.

Effectiveness of SCS Assistance to Georgia Landowners

SCS has been assisting Soil and Water Conservation District's for 39 years in an effort to reduce soil erosion, and effectiveness of this assistance needs to be discussed.

As was pointed out, the conservation plan is the tool used to get conservation on the land. Conservation plans have been developed for 97,500 decisionmakers and partially completed for 9,000 more. However, a good plan is only as effective as the amount of needed conservation measures applied to land and properly maintained.

SCS planners have assisted decisionmakers in applying cropping systems at an annual rate of 250,000 acres per year.

As previously discussed, the cropping system is one of the factors which determine the potential erosion that can occur.

Critical area treatment is also an important item in reducing erosion. These are areas which are subject to severe erosion and can be properly treated with vegetation, or with vegetation and mechanical practices. These areas are being treated at an annual rate of 3,500 acres per year.

Vegetated waterways are being constructed, vegetated, and used in water management systems at an annual rate of 550 acres.

Terraces and diversions are being constructed at an annual rate of 2,700,000 feet. These are effective mechanical practices in the erosion control system.

Ponds, debris basins, and grade control structures are being utilized in water management systems and are being built at a rate of 1,500 per year.

Items Which Have Affected and Are Now Affecting Implementation of Sound Conservation Systems

There are several factors which affect the establishment of sound conservation systems.

The recent removal of planting restrictions by the U.S. Department of Agriculture can endanger the conservation program if proper erosion and water management systems are not considered. This program could bring marginal acres of potentially erodible land back into crop production, so an erosion and water management system needs to receive proper consideration. Secretary Butz, in announcing the removal of planting restrictions emphasized, and rightfully so, the need for farmers to use good conservation measures as they increase crop production. But the fact remains: good conservation practices must be used if we are to avoid severe erosion problems on some of these areas.

Multirow farm equipment with rigid tool bars caused many farmers to go back to farming up and down hill rather than following the contour. Many well-planned and well-constructed parallel terrace systems have been destroyed by farming over them. However, by using turn rows and by designing the terrace to fit the equipment, large equipment can be used with parallel terraces. In addition, large farm tractors can be used to build and maintain terrace systems much easier now than ever before.

Contractural farming in many instances has also hurt good conservation farming. Farming operations have gotten bigger. To do this, farmers have acquired allotments and land to grow cotton and peanuts and soybeans. These operations are not always as conservation-concerned as they should be. This gets away from a farmer working his own land and, in general, taking much better care of his land.

Farm labor has been on the decrease. This has caused many a farmer to buy more and larger equipment so he can perform all the work himself.

The number of SCS personnel available to provide assistance to land decisionmakers has also been on the decrease. Our numbers have been reduced by 17 percent over the past 2 years. This reduces our ability to assist those who need help with their conservation problems.

Conclusion

Conservation planning is the key to getting cropping systems, water management systems and erosion control systems applied in a logical and systematic manner to control erosion. All components of the plan must be based on sound standards and specifications.

In developing the plan, the conservationist must use an interdisciplinary approach with the decisionmaker so proper consideration can be given to his objectives.

However, if the plan is to be effective, the planned measures must be applied on the land and maintained. Planned measures, properly applied to land, will keep erosion within tolerable limits so the land can be cropped over a long period of time.

Therefore, it is the responsibility of every individual to be a good steward of the soil. The soil is a most valuable resource and must be managed wisely.

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Chapter 7

FORESTRY IN WATERSHED MANAGEMENT

A. R. Shirley

Throughout the history of our nation, our essential natural resources have been taken for granted, by the American people, due to their abundance.

Beginning in the 1930's with a dwindling supply of quality water, air fouled with noxious gases, streams running red with silt and loss of fertile food producing land, the very stuff that supports life, a different attitude began evolving. As a result many sound conservation programs were begun.

Many water retention reservoirs have been constructed providing water-based recreation, skiing - boating - fishing - however, the principal reason for impounding the water was, and still is, to prevent damage to farm lands - crops - property - homes - highways - and energy or electrical power.

Thousands of eroded, nonproductive acres and mud filled rivers which were formerly in the South and many other parts of the country have been reclaimed for beneficial use. However, the job has not been completed and we must continue to improve in many areas.

After generations of closing our eyes to the uncontrolled rampaging of our water beyond its natural boundaries, local citizens and governments have taken action through watershed management.

A watershed is any given land area that drains into a single stream. It may be as small as your farm, or as large as the nine hundred million acre drainage area of the Mississippi River.

A watershed is more than the hills or valleys of the countryside. It includes the cities, roads, farms, forests, and people. Wherever you are, whatever you do, your life is affected by the watershed in which you live. Water is stored for municipal, industrial and recreational uses, thereby contributing to the health and economic welfare of the community.

The enactment of the small watershed program in recent years was most timely because it began during a period of rising concern for our environment.

It is the only program that is involved with all of the elements of healthful, happy living such as: water - soil - air - forests - recreation.

Clean water the year round, and plenty of it, is essential to progress in growing Georgia. Georgia has more than four feet of precipitation in the average year. Well managed watersheds are able to convert most of this moisture into useful water for agriculture, industry, domestic needs, irrigation and recreation. When watersheds are in poor condition, a large part goes to waste, producing floods and erosion. The amount of stormflow leaving Georgia watersheds as potential flood waters amounts, on the average, to only ten percent of the annual precipitation, according to a recent study by Professor John Hewlett of the University of Georgia School of Forestry Resources.

Thousands of tons of silt, comprised usually of the most fertile soil from the tributary watersheds, are carried off by Georgia's rivers every year. Excessive silt in a stream is the result of uncontrolled runoff, poorly managed agricultural lands, woodlands and pastures, unprotected highway embankments and urban developments.

Heavy silt loads, carried by flood waters, are deposited on the river banks or in the channels. The result is damage to bottom lands and a reduction in the carrying capacity of the streams. Most measures designed to reduce floods on the uplands will also alleviate damage due to erosion and silting. These damages are kept to a minimum on well managed watersheds.

Pine forests add less organic matter and minerals to streams than hardwoods because the pine straw tends to lie where it falls. For this reason pines are often planted around water supply reservoirs and catchment areas.

Forest operations and harvesting have their main influence on water quality through the accompanying release of sediments and dissolved materials as well as the change in water temperature. The damages are apt to be severe only when these activities are concentrated near the stream network.

Forests are the greatest source of photosynthetic activity, taking carbon dioxide from the atmosphere and releasing oxygen as a by-product. It is important for us to recognize this function and the role forest play, not only in supplying products and recreation demands, but in providing basic requirements for life.

In addition to the many benefits the small watershed dams provide in controlling erosion and preventing floods, it also fulfills the need of the average person, with limited time, by providing him a place for fishing and aquatic recreation.

A major contribution to the purity of our environment, made by the forests, is that they function as excellent regulators of the water supply. Water reaches the earth from the atmosphere in the forms of rain, snow and, to some extent, fog. Part of the moisture is returned to the atmosphere by transpiration, and is returned to earth again in a never-ending cycle.

Through the process of transpiration, trees give off enormous amounts of water during the growing season. An acre of large trees will transpire one million, six hundred and fifty gallons during the hot summer months.

By serving as the main source of clean water to fill streams and recharge ground water, Georgia's twenty-six million forest acres produces about sixty-one percent of the state's total useable supply...that is, the useable part that remains after consumptive evaporation has been deducted from the annual precipitation. The computed present value of forest water to the state, over and above the water's value in the absence of forest, approaches a billion dollars. The calculation neglects the value of forest water evaporated in producing the state's largest crop, wood.

What are some of the advantages of having an abundance of forest land? Right off, we think of the thousands of products which come directly from trees (lumber, pulp and paper, chemicals, etc.). The forests also have a moderating effect on the temperature. Forest floors are slightly cooler in summer and warmer in winter than the surrounding air.

A particularly important hydrological benefit of the forest is its annual crop of litter, leaves, steams, needles and other debris. It is not the crowns of the trees, but rather the debris on the ground that serves most to disperse the energy of falling rain. A raindrop striking the ground at about fifteen feet per second is possessed of surprising energy if its velocity is not broken by fibrous material. Georgia's fifty inches of annual precipitation is calculated at about forty million foot pounds per acre. This is enough to lift the top foot of soil ten feet in the air if applied all at once. Part of this energy was sufficient over the last one hundred years to remove one foot of soil from the piedmont under cotton and corn cultivation.

The average Georgia forest produces from one to two tons of debris (dry weight basis) per acre per year, forming a loose, energy-absorbing layer one to three inches deep over the soil. The growth and depth of roots just beneath the surface also absorbs energy and binds the surface soil into a mat that resists erosion after fires, at least until regrowth of sprouts and herbs take over.

On nearly every Georgia watershed, almost two-thirds of the area is in woodland. Trees, then, play a vital role in the small watershed program. Idle land is reforested for its own protection, and to protect the land in the lower reaches of the watershed from silt and other erosional debris.

Forested land is protected from fire and overgrazing. Timber cutting is held below the growth rate to permit the formation of a good forest litter. Forests play a key role in the preservation of our game and wildlife, and in the development of recreational areas.

And, forests are the greatest stabilizers of the soil. A stream, whose drainage area is covered with trees, nearly always runs clear. Results - the land is better covered and more rain soaks in. Runoff and silt damage to stream channels, reservoirs and bottomlands is reduced.

I feel it necessary to point out here that if forestry interests in Georgia do not take an active part in forest-water research, foresters may find themselves relatively ignorant in future public debates over the allocation and protection of water supplies, because those interests that elect to do such research will have the advantage of interpreting the role of forestry in water resources.

Land and water problems, in the very beginning of the watershed are dealt with in a thorough program for maximum conservation results that are beneficial not only to those that may have title to the land, but are of multiple value to all the people in the area, region, state and nation.

These values include conservation of soil and water for erosion control, flood control, storage of water for agricultural, industrial, community needs, recreation fishing, boating and other uses; planned cover crops of trees and other plants on critical slopes and submarginal soils; and grasses and crops on lands of well planned conservation guidelines.

These conservation practices have resulted in increased bird and wildlife population and hunting and fishing opportunities for all people.

Cities and towns have greatly benefited from increased water supplies for present and future needs. In many towns and cities, industry has expanded and new industry has come in as a direct result of the small lakes created in the watersheds for multiple use.

The Tobesofkee Lake created on the outskirts of Macon is an excellent example of the value of the program to a city - county and area.

Thousands of people are offered a place for recreation and other uses- the parks, fishing, water sports, boating, water supply for future growth in the area, flood control and contributing a better environment - and the lake is located near enough for the low to medium income family to use and enjoy regularly.

This program should be enlarged so that similar facilities could be extended to as many towns and cities as feasible. Lakes of one hundred acres to one thousand acres in size within five to fifteen miles of a town or city are needed for multiple use.

As a result of these watershed programs in Georgia, we have, today, more people fishing, more places to fish and more fish caught than ever before. The same is true of hunting. Streams are cleaner and clearer, and there is less soil erocion and flooding than at anytime in the past sixty to seventy-five years.

A major objective of a watershed is to increase the water intake thus reducing flooding and erosion and increasing land values.

Man uses reservoirs to control floods and for water storage for farm, municipal, industrial and recreational uses. However, he sometimes creates conditions that cause these reservoirs to be filled with sediment thus making his own water problems.

The availability of water is largely due to land use. This makes a land capability map the logical place for a land manager to begin water control. Through this map, the land manager will advocate using only that portion of land suitable for a specific crop. Slope, soil type, moisture and physical obstacles are noted on the map. A farmer, using such a map, could realize a maximum profit from his farm, and at the same time practice water conservation.

Experiments on watersheds show us that forest cover results in greater watershed protection without a measurable decrease in water yield.

Dams regulate stream flow and trap sediment giving prompt relief down stream. However, unless the area is stabilized, such as forested, its usefulness is short lived.

The sediment load of a stream is greatly affected by forest cover. The greatest reduction in sediment accumulation is realized in the first few years after a forest is established or improved.

The farmer is concerned with stream flow, especially the peak discharges during the summer. Where forests have been established, the peak summer discharges have been markedly reduced, which, in turn, reduces the damage to row crops in the area. This result alone is cause for the farmer to practice good watershed management through the use of trees.

To a farmer, the forest is an important part of watershed management. The forest prevents water losses, causes snow to melt more slowly, prevents floods and increases the quality of water. The farmer concerned with watershed management can, in many cases, control undesirable circumstances through the use of sound forest management.

Over the past nine years, the National Watershed Congress has recognized two Georgia watersheds as "Watershed Of The Year". The Little Tallapoosa Watershed was named in 1965. Industry expansion and establishment and flood control have resulted from the sixty-two thousand acre watershed. In 1971, the Bull Creek Watershed between Pine Mountain and the Chattahoochee River near Columbus was honored. This was the first urban endeavor with the primary objective being the establishment of a combination of land treatment and structural measures which provides full protection for the main part of the residential and other urban areas for a one hundred year frequency rainfall runoff.

At present, there are thirty active watersheds in Georgia involving three point nine million acres in approximately ninety counties. In the watersheds, the Georgia Forestry Commission has the responsibility for developing forest work plans, conducting critical area planting on areas designated by the Soil Conservation Service, furnishing technical assistance and providing fire detection and suppression facilities.

Watershed projects can bring prosperity to an entire area along with flood prevention, agriculture water management, scientific land treatment, water-based recreation and fish and wildlife development.

There is no such thing as "lost" water. The water that evaporates each year from Georgia rejoins the global water supply, sustaining the normal circulation of the continental water cycle. The "lost" water favors the growth of forests, pastures and crops at the site where the moisture evaporates. So, it is used after all.

Nor is the water which flows unchecked into the sea entirely wasted. Such water, in transit fills the state's streams, reservoirs and ground water bodies, and serves as a diluent and carrier for both human and natural wastes. Therefore, the entire ebb and flow of the hydrologic cycle over Georgia is constantly working for the people. It is evident that some portions are overworked as in the case of streams overloaded with waste, overdraft of ground water by pumpage and the over-taxing of soil water storage by plants during droughts.

What is perhaps overlooked by many Georgians is the fact that our expansive forest acreage play an intricate and often predominant role in various aspects of the state's water resources.

The success of the small watershed program and all conservation programs depends largely on all resource development agencies and organizations working together. Each of these have more in common than they have differences. They should and must support each other, emphasizing each other's virtues and helping overcome any weakness.

After the war between the states, that great Southern editor, Henry W. Grady, went up and down this country waving the banner of the South, saying "Cattle will graze in a million valleys, happy farmers will dwell in the midst of luxuriant fields and laughing children will play in the shade of green forests and wade in the water of clear streams".

The small watershed program in Georgia is helping to make all this a reality.

Chapter 8

MANAGEMENT OF WETLANDS FOR AGRICULTURAL PRODUCTION, WATER STORAGE AND RECYCLING: ALTERNATIVE USES

Frank D. Whisler

ABSTRACT

Wetlands have been drained in the past and put into agricultural production many times to the detriment of the soil and surrounding ecosystems. In view of economic analysis only those areas separate and apart from main streams or swamps can be unequivocally drained and placed into production. Other areas must be systematically analyzed before draining. With the recent removal of quotas on rice, it would seem the most likely crop for former wetlands. Very precise watertable control may limit the degradation of wetland soils and organic matter contents.

Wetlands have a valuable place as a water storage source for both rural and urban areas. They can also double as recreational sites.

The recycling of nutrients and water in wetlands may be possible, again with careful watertable controls. The use of such sites for waste water disposal appears to be a fruitful area for research.

MANAGEMENT OF WETLANDS FOR AGRICULTURAL PRODUCTION, WATER STORAGE AND RECYCLING: ALTERNATIVE USES

Frank D. Whisler [1]

A discussion of wetlands is often an emotional one if there are several persons from varying backgrounds involved. To the average farmer, agronomist, or engineer they are generally viewed as liabilities and obstacles to agricultural or industrial development. Wetlands, encroaching the boundaries of a particular farm, are viewed like a corn plant in a soybean field; productive in their own right, but definitely out of place. On the other hand the conservationist, ecologist, wildlife biologist and water resource developer views wetlands as assets in themselves. A rose is a rose is a rose. It is appropriate, therefore, to look at these areas in terms of agricultural productivity, water storage and recycling.

In view of the diverse backgrounds of the participants and audience of this symposium, a few definitions are in order. Wetlands involve wide variations in extent or durations of wetness and sources of water. There have been 20 types of wetlands proposed as a classification scheme (8). The types widely distributed in Georgia are briefly described and listed below.

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Additional words for indexing: Drainage, Land Use Alternatives, Nutrient Recycling, Waste Water Recycling, Nitrogen Removal, Phosphorus Removal.

Seasonally Flooded Basins or Flats

The soil is covered with water or water-logged during variable seasonal periods, but usually well drained during much of the growing season. Along river courses, flooding ordinarily occurs in late fall, winter, or spring; in upland areas, basins or flats may be filled with water during periods of heavy rain or melting snow.

Such areas are located on river bottoms in various parts of the country, particularly in the Mississippi Valley, and along the borders of drawn-down reservoirs and in "dry lakes" shallow potholes, and other shallow upland depressions in the West, and elsewhere.

The vegetation varies greatly, depending mainly on the season and duration of flooding. It includes bottomland woods as well as herbaceous growths. In marginal zones where the water has receded early in the growing season, smartweeds, wild millet, fall panicum, tealgrass, chufa, redroot cyperus, and cockleburs are likely to occur. Shallow basins that are submerged only very temporarily usually develop little or no wetland vegetation.

Fresh Meadows

These are areas of soil without standing water but waterlogged within at least a few inches of its surface during the growing season.

Located principally in glaciated country in the northern States, in the Nebraska sandhills, and in Florida, but also Georgia fresh meadows may fill shallow lake basins, potholes, limestone sinks, sloughs, or farmland sags, or may border shallow marshes on the landward side of such depressions.

The vegetation is made up of grasses, sedges rushes, and various broad-leaved plants. In the South, representative species include paspalums, dotted smartweed, and beakrushes.

Open Fresh Water

This is water of variable depth.

It is located principally in glaciated country in the northern States, and in the Nebraska sandhills, Florida. and Georgia. It also occurs in artificial ponds, lakes, and reservoirs throughout the United States. Open water may completely occupy lake and pond basins, potholes, limestone sinks, sloughs, or stream beds, or it may be fringed with marsh.

Vegetation (mainly at depths less than 6 feet) consists of pondweeds, naiads, wildcelery, coontail, watermilfoils, muskgrasses, waterlilies, spatterdocks, water-hyacinth (in the South), and other aquatics.

Shrub Swamps

The soil is normally waterlogged during the growing season; often covered with as much as 6 inches of water.

Such areas are located principally in glaciated country in the northern States, along the Atlantic Coastal Plain, and in the Mississippi Valley. Shrub swamps occur mostly along sluggish streams and occasionally on floodplains.

The vegetation consists of alders, willows, buttonbush, dogwoods, swamp-privet, etc.

Wooded Swamps

The soil is waterlogged at least to within a few inches of its surface during the growing season, and often covered with as much as one foot of water.

Such areas are located in glaciated country in the Northeast and Lake States, in lowlands of the Northwest, and along the Atlantic and Gulf Coastal Plains. They occur mostly along sluggish streams, on floodplains, on flat uplands, and in shallow lake basins and potholes.

The vegetation is mainly trees; in the South, representative species are water oak, overcup oak, tupelo gum, swamp black gum, and cypress.

Bogs (often called pocosins, bays, and savannahs in the South).

The soil is usually waterlogged; generally blanketed with a spongy covering of mosses or other plant material.

Such areas are located in glaciated country in the Northeast, Lake States, Northwest, western mountains, and along the Atlantic and Gulf Coastal Plains, mostly in shallow lake basins and potholes, on flat uplands, and along sluggish streams.

The vegetation is woody or herbaceous or both; typical plants are heath shrubs, sphagnum moss and sedges. Representatives of the vegetation in the South include cyrilla, persea, gordonia, sweetbay, Virginia chainfern, and pitcher-plants. Scattered, often stunted, pond pine may occur in southern bogs.

In its natural state wetlands are used as nesting, shelter and feeding areas for waterfowl, song birds, wild turkeys, deer, small rodents, and other wild life as well as fish habitat where the area is continually flooded. The effects of stream channeling has been to drain some of these wetlands and make such areas unusable for much of the wildlife (2). Drainage projects have also had the same effects. According to the Soil Conservation Service there are 11, 775,000 acres classified as wetlands in Georgia. 2/

Agricultural Production

The first item to come to mind when discussing wetlands and agricultural production is drainage. Table 1 shows the acres in farms in Georgia in 1960 and 1969 as well as the acreages in drainage projects at these same times.

It is seen that while total farm acreage has declined by almost 36% over this decade, the amount of drained acreage increased over 1,400%. It is also of interest to note that non-cropland drained acreage also increased a whopping 50,230%. In 1960, this kind of acreage amounted to only 0.008% of the total farm acreage but by 1969 it accounted for 6% of the total farm acreage. What use is made of this land is unknown (probably forested areas), but presumably it is not for urban development.

2/ Personal communications from Glenn L. Bromlett, SCS, Soil Correlator.

Table 1. Acreage increases in Georgia drainage projects. 1960-69 (11).

Date	Total Acres in Farms	Total Acres in Drainage Projects		Total Drained Acres in Non-Cropland	
		acres	% of Total	acres	% of Total
1960	19,657,615	94,728	0.5	1.500	0.008
1969	12.645,090	1,424,173	11.3	754.928	6.0
% Increase	-35.7%	1,403.4%		50,230%	

Acreages of installations of new drainage projects in 1969 are shown in Table 2. This table shows that there were over 184,000 acres of farm land placed in drainage projects during the year or 13% of the total acreage of such land. In looking at the actual acres drained, however, there were only 9,600 acres added in 1969 or a 5% increase for the year. (An entire farm when placed in a drainage project is counted as total acreage, Column 2, but the actual drained acres are less, Column 3.) Presumably the same rates of drainage are going on today.

The uses of these drained acres are shown in Table 3. About 30% of the total farmed acreages in drainage projects are in harvested cropland and 9% is in pasture land, but 53% is in non-cropland.

The economics of draining wetlands has been studied recently for the midwest by Goldstein. In general, he showed that where price supports are maintained for agricultural crops, it is profitable to install drainage; however, in a totally free market the reverse is true. In view of the recent price increases and dispensing with allotment quotas on rice, Goldstein's free market has been achieved but not as he assumed. Thus, his conclusion should be taken carefully. In his study, he does try to evaluate the recreational aspects of wetlands and he also studies the advantages and disadvantages from both the private sector and public sector of the population. In general, if a wetland area is isolated and within a single farm boundary, it

Table 2. Drained Land in Georgia as of 1969. (11)

Total Acres in Farms	Drained		New Installations in 1969	
	Total Land in Drainage Project (acres)	Total Land Drained (acres)	Total Land in Drainage Project (acres)	Total Land Drained (acres)
12,645,090	1,424,173	193,486	184,850(13%)*	9,631 (5%)*

*% of drainland, Col. 2 and 3, respectively.

Table 3. Uses of Drained Land in Georgia as of 1969 (11).

Total Land in Drainage Project	Harvested Crops		Pasture or Grazing		All Other Cropland		Non-Cropland	
	acres	%	acres	%	acres	%	acres	%
1,424,173	433,696	30	119,664	9	115,885	8	754,928	53

would pay to drain. If it is adjacent to a stream or extensive swamp then many factors must be evaluated to check the economic feasibility of drainage.

Besides the cost factors and loss of recreational lands, there are other problems of drained wetlands. There is often land subsidence of drained areas where the organic matter content is high (4). In addition to this problem the organic matter often rapidly oxidizes leaving the soil in poor physical condition (4). These problems might be avoided with close control of the water table by the drainage system such as designed by Willardson, et. al. (14). These authors have proposed tile lines in which the outlets are higher than the general field tiles which will usually keep the field tiles submerged providing an anaerobic environment. Such an arrangement is helpful in controlling manganese and nitrogen problems (as will be discussed later) and also provides a close control of water tables if coupled with outlet valves.

The crop most often recommended for drained wetlands is rice. With the recent removal of acreage allotments on this crop, increased useage of reclaimed wetlands for such production seems both profitable and feasible. Other crops grown in such areas are blueberries, cranberries, sugar-cane (in proper climates) as well as forages such as reed canarygrass and bermudagrass (8).

Such land is often used for forests (8,9). Read, et. al (9) has evaluated and recommended a bedding system, called "riggs and furrs" where the planted soil is mounded 8-10" high between 36-48" furrows of such land for tree growth because of favorable moisture and aeration in the soil. Such land shaping practices are used for the production of cotton and soybeans in Mississippi and should be feasible in reclaimed wetland areas where soil aeration might be a problem for crops other than rice.

The natural productivity of such soils is generally high. If there is a high organic matter content present, heavy applications of nitrogen may be needed, depending upon the crop, in order to offset microbial tie up of nitrogen in the breakdown of the soil organic matter. The additions of other fertilizer elements and lime should be made to such land only as recommended following soil tests.

Water Storage

Wetlands are natural areas for storage of fresh water either for rural or urban uses (4). Such areas may be as valuable to farmers for temporary storage of supplemental irrigation water and water for livestock as it would be under more intensive practices. Wells drilled in such areas can be quite shallow, depending upon the soil material, but still highly productive.

Urban use of wetlands for water storage could have an added attraction, recreation. Such an area can be set aside as a wildlife refuge where nature trails, possibly fishing, boating and other water based sports can be enjoyed but serve a dual purpose as a water supplier. Such areas near the ocean also serve as a barrier to salt water intrusion into a fresh water aquifer.

The quality of water in a wetland area will depend upon the watershed from which it is derived. In general, however, we are talking about fresh water areas from agricultural or forested watersheds and, therefore, the water should be of fair quality, ie. probably have a high fecal coliform count in the surface water, but be low a few feet below the soil surface (10).

Recycling

There are two quantities that can be included in the term recycling--nutrients and water. The foresters have made extensive studies of nutrient recycling under different forest management regimes (12,13). A pulpwood harvest removes only about 1/3 of the nutrients removed in clear-cutting. Seasonally flooded basins with their naturally highly fertile soils would probably not need additional fertilization under such management. Such has been the case for the Mississippi flatwoods area and Loblolly pine. Yet the bogs of North Carolina are very unproductive for any forest species.

Agronomists have been aware of the nutrient balance and recycling effects for a long time and have worked out cycles for the individual elements in the environment. In general, however, with the growth of most field crops, some nutrients have to be added occasionally in the form of fertilizers to the soil to maintain a productive agricultural enterprise.

The use of wetlands for the recycling of waste water has some promise along with some problems. While this topic of land use for waste water disposal is someone else's topic, I want to inject some of the experience I gained while working with a team of scientists and engineers on this problem at the U. S. Water Conservation Laboratory in Phoenix, Arizona. The big problem with waste water disposal into natural bodies of water is increased eutrophication due to high amounts of added nitrogen, phosphorus and, perhaps, carbon. Agronomists have known for a long time that under ordinary pH ranges (pH 4-8) soils will "fix" large amounts of phosphorus in insoluble forms; therefore, land disposal of waste water has been suggested (1,5,7).

The nitrogen problem is a little harder to solve, but, seemingly, not impossible. Most of the nitrogen in waste water, either municipal or agricultural, is in the ammonium or organic form, but when applied to well aerated soils is easily converted to the nitrate form (5,6) (Figure 1). This figure illustrates the fate of nitrogen in waste water when it is applied to the soil. Which pathway is taken will depend on the pH and aeration or oxygen supply of the soil. The nitrate ion is not fixed in the soil but is easily leached from the soil to streams or groundwater table if it is not denitrified. With sufficient carbon and low oxygen levels, the nitrate will be microbiologically denitrified. Wetland soils generally have both requirements, high organic matter (ie. carbon contents) and low oxygen levels.

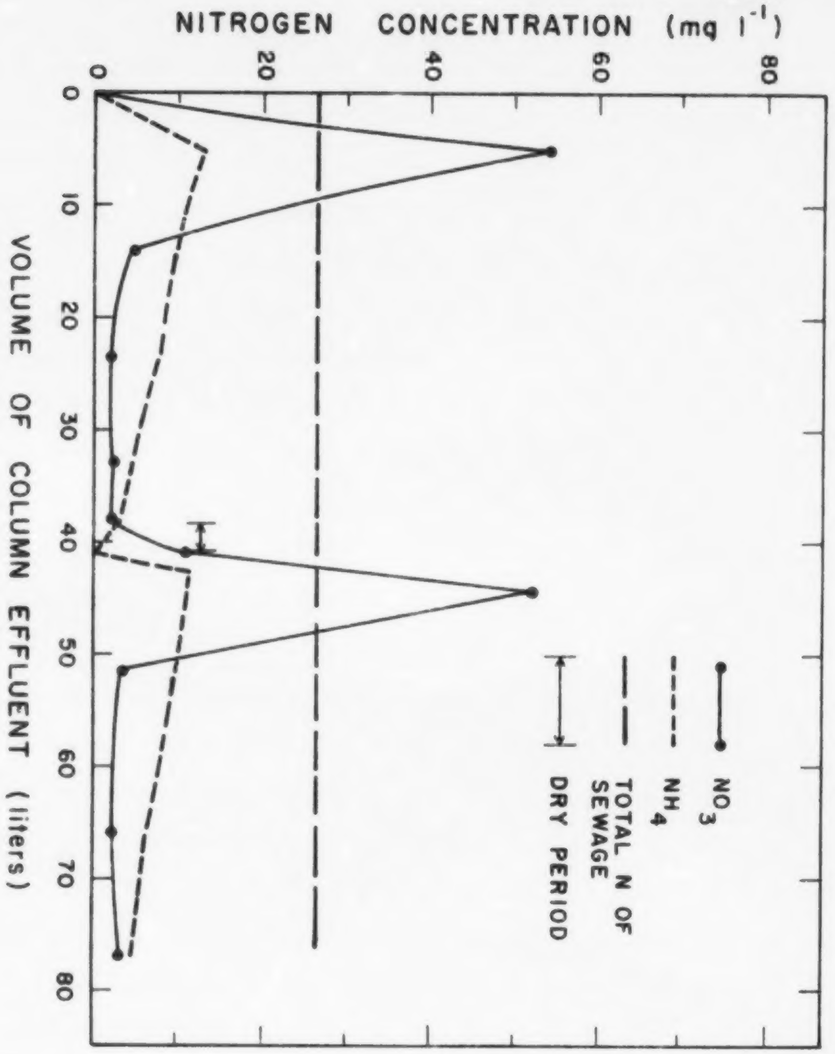

Figure 1. Nitrogen transformations during land disposal of waste water.

A recharge basin-drain system like that proposed by Bouwer (1) shown in Figure 2, could be used to collect the applied waste water and either recycle it or discharge it into a stream. The additional travel beneath the water table to distant tile lines as in part A or alternately opened tile lines as in part B and C will provide added filtering for bacteria, viruses and phosphorus. The reason for recycling some of this water again is pointed out in Figure 3 from Lance and Whisler (6). This Figure shows the nitrate and ammonium ion concentration versus volume of applied effluent for a nine day flood, 5 day dry cycle of recharge. At the start of a new recharge period (the dry period is necessary to restore basin infiltration rates) the water has a very high nitrate content. This is quickly reduced and accounts for about 10% of the volume. If the drain system in Figure 2 were designed so that the first water collected could be recycled through the basins, 70% or more of the nitrogen could be removed.

Table 4 shows the efficiency of several systems of nitrogen removal (1). In addition to recycling, using lower infiltration rates also aids in nitrogen removal. Thus, a combination of management alternatives are available in handling waste water recycling.

Summary

Where wetlands exist isolated from streams or swamps, drainage and use for agricultural production appears to be economically sound and feasible. Crops such as rice or

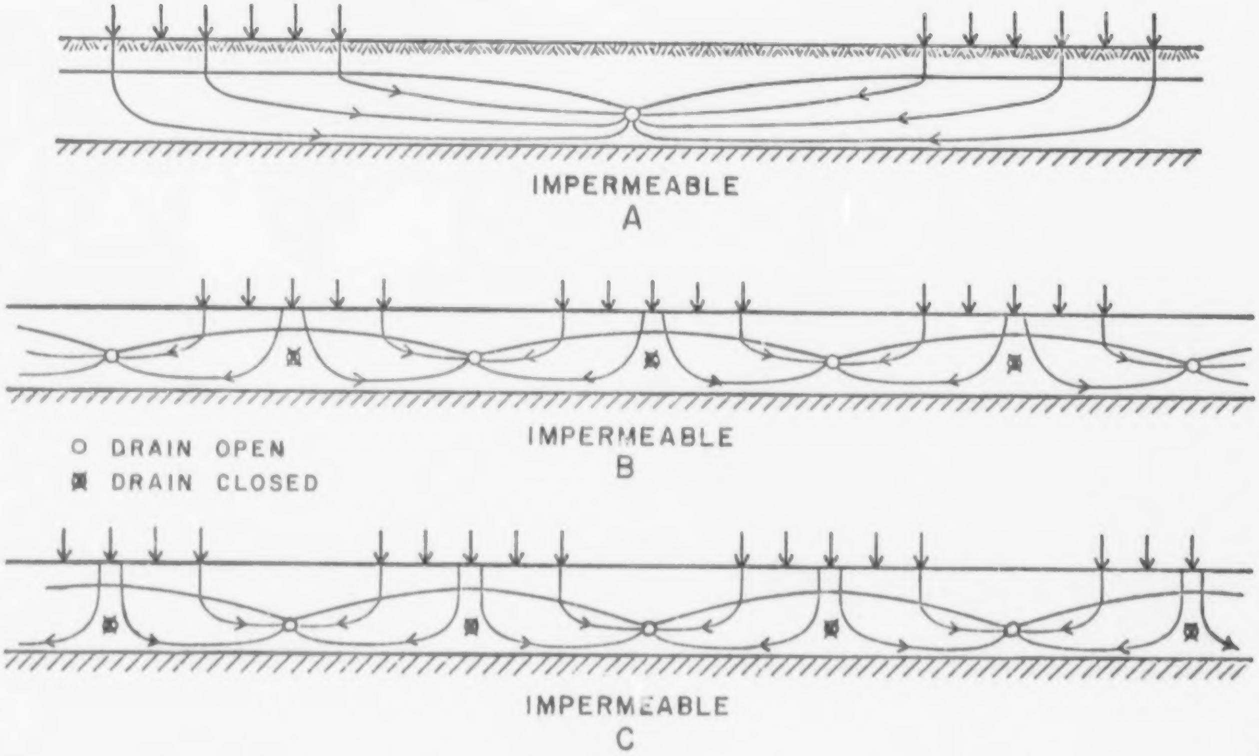
IMPERMEABLE
A
IMPERMEABLE
B
○ DRAIN OPEN
☒ DRAIN CLOSED
IMPERMEABLE
C

Figure 2. Two parallel infiltration strips with drain midway between strips (A) and continuous system of infiltration strips and drains with alternate infiltration and drying (B and C).

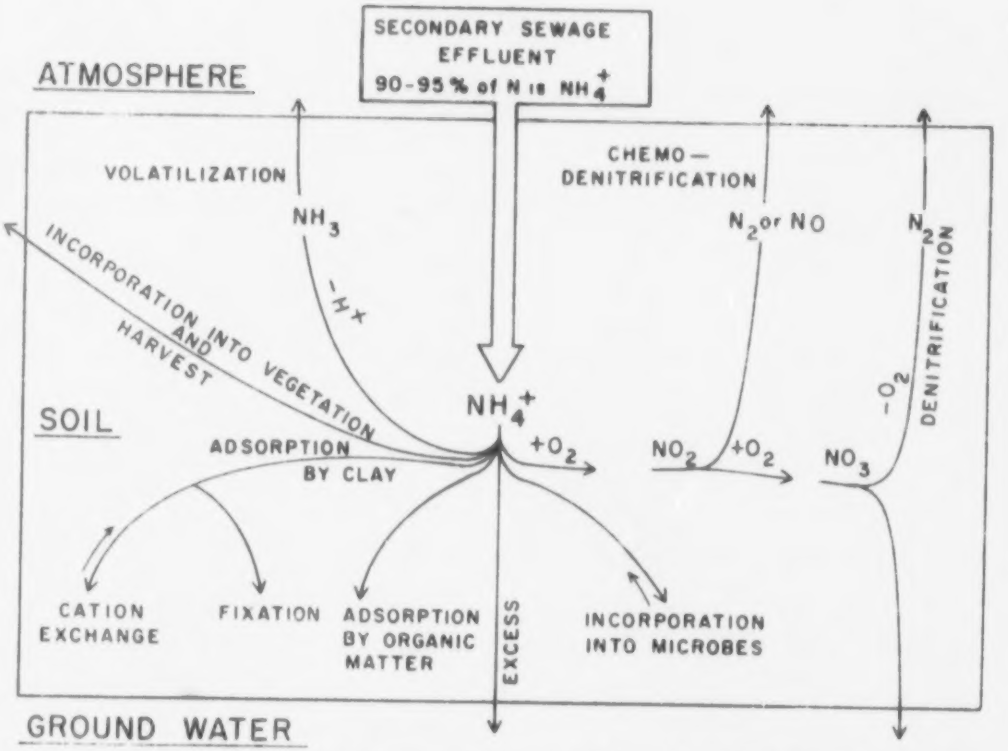
SECONDARY SEWAGE
EFFLUENT
90-95% of N is NH_4^+
ATMOSPHERE
VOLATILIZATION
NH_3
$-H^+$
CHEMO—
DENITRIFICATION
N_2 or NO
N_2
DENITRIFICATION
$-O_2$
INCORPORATION INTO VEGETATION
AND
HARVEST
SOIL
NH_4^+
$+O_2$
NO_2
$+O_2$
NO_3
ADSORPTION
BY CLAY
CATION
EXCHANGE
FIXATION
ADSORPTION
BY ORGANIC
MATTER
EXCESS
INCORPORATION
INTO MICROBES
GROUND WATER

Figure 3. The change in N concentrations with volume of couumn effluent during 2 cycles of 9 days flooding and 5 days drying. Data are averages of three columns. Area under arrow represents the volume of drainage water collected during the dry period.

Table 4. The percent N removal and volume of reclaimed water obtainable with different management systems.*

Treatment	N Load (kg/ha)	Infiltration (cm/day)	% Removal	Capacity** (m/yr)
Recycle	16,000	33	76	60
Recycle	12,000	25	81	45
Low infiltration rate	12,000	18	75	45
Low infiltration rate	10,000	15	80	38
High infiltration rate	22,500	35	30	85

*Estimates are based on a schedule of 10 days flooded and 5 days dry.

**Represents the net volume of reclaimed water.

forages such as reed canary grass are ideally suited to such areas.

Wetlands have a real value as a water storage source for both rural and urban developments. They also can serve a dual purpose as recreational and wildlife habitat areas.

Wetlands can be used for waste water recycling. Their naturally high organic matter content and low oxygen status make them ideal for nitrogen removal from such waters.

Research Needs

In view of the past years economic upheavals for agricultural products, studies such as those of Goldstein (3) need to be reevaluated. Such work, however, should involve a team of scientists and administrators for the problems of alternative uses of land and water resources are far beyond the scope of any one discipline. Agriculturalists, economists, mathematicians, computer scientists and engineers must all be involved in such studies if the results are to be meaningful and realistic.

The use of wetlands as sites for waste water reclamation or disposal has been proposed. A pilot project such as the Flushing Meadows project in Phoenix (1,7 and references therein) should be tried, together with control tile lines as proposed by Willardson, et. al (14). Again, a team of scientists and engineers will be necessary to evaluate such a project.

Our water resources and land resources are two of our most valuable natural resources. We need to learn how to use them and reuse them and not abuse them now and in the future.

Acknowledgements

The author wishes to acknowledge the able assistance of Dr. Judy K. Young in collecting the background references for this article.

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Chapter 9

TIMBER POTENTIALS IN THE WETLAND HARDWOODS

Stephen G. Boyce and Noel D. Cost

ABSTRACT

The wetland hardwood forests in the States of Virginia, North Carolina, South Carolina, Georgia, and Florida occupy 12 million acres of wetlands. These forests contain 21 percent of the total growing stock in the Southeast. Growth and removals are lower and mortality is higher than for the other forest types in the Southeast. Analyses were based on Forest Survey data. The dominant species are tupelos, sweetgum, the wetland oaks, cypress, ash, and soft maple. Fifty-seven percent of the growing stock is in soft-textured hardwoods. Almost half of these forests occur on stream margins and about one-forth are in swamps, bays, and wet pocosins. The remainder are in flatwoods, dry pocosins, cypress ponds, channels, and rolling uplands. An analysis of a recent surveyed area is southeastern North Carolina suggests a potential average growth of at least 70 cubic feet per acre per year on 10 per cent of the area without culture. It is likely that growth for all the wetland hardwoods can be considered increased. A more useful classification of wetland hardwood communities must be developed. Growth and yield functions must be prepared. Research is needed to discover ways to regulate stand density and water, control species composition, regenerate stands, improve genotypes, and apply nutrients.

TIMBER POTENTIALS IN THE WETLAND HARDWOODS

Stephen G. Boyce and Noel D. Cost [1]

Wetlands of the Southeastern United States include communities of shrubs, forests, prairies, and marshes. More wetlands occur in the Southeast than in any other portion of the country (8). These lands are valuable as habitat for many kinds of birds, fishes, insects, and mammals. These lands are important also for storage of both surface and ground water. Some of these lands are the major source of hardwood timber for manufacture of furniture, plywood, veneers, and fiber products.

In this report we describe the wetland hardwood forests of Virginia, North and South Carolina, Georgia, and Florida; and we try to roughly estimate the potentials of these forests for timber production. Perhaps most important, we list the gaps in knowledge that must be filled if we are to make wise decisions for the protection and use of these forests. These gaps exceed the filled-in areas in many instances.

Procedures

Plot data from the Forest Survey of the U. S. Forest Service are our primary source of information. We have included as wetland hardwood forests what Forest Survey defines as the oak-gum-cypress and elm-ash-cottonwood types (5, 16, 20). Plots dominated singly or in combination by the tupelos, sweetgum, wetland oaks, or cypress are classified in the oak-gum-cypress type. Plots dominated singly or in combination by elm, ash, or cottonwood are classified in the elm-ash-cottonwood type.

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In the Southeast cottonwood is uncommon and elm and ash rarely occur as dominants on large areas. These species commonly occur in mixture with other species of the oak-gum-cypress type. Thus, oak-gum-cypress is by far the more common type in the region.

The information from survey sample points that we use in this report includes species, ages, diameters, and heights of the trees, physiographic class, and a description of general forest conditions. South Carolina, Florida, and Georgia have been surveyed four times and Virginia three times at intervals of about 10 years. North Carolina is now in its fourth survey. In this paper we use data from both the third and fourth surveys.

Plots classified as oak-gum-cypress and elm-ash-cottonwood were plotted on maps to locate wetland hardwoods in the region. From these maps and from plot data, we identified counties where wetland hardwood forests are important for timber production. We searched the literature for information on site index, volume tables, growth predictions, and related silvicultural studies of these forests. In a recently surveyed area in southeastern North Carolina we examined volume growth on plots remeasured after 11 years, and we related this growth to stand composition, density, age, and physiographic class.

Forest Description

Wetland hardwoods grow on the margins of streams that are frequently flooded; in swamps, bays, and wet pocosins where the water may stand for long or short periods of time; and in depressions and poorly drained areas of the flatwoods, dry pocosins, rolling uplands, and narrow streams of the Piedmont. Interspersed among the stands of wetland hardwoods are forests of pond pine, longleaf pine, slash pine, loblolly pine, upland hardwoods, and the oak-pine forest types. These interspersed forests are not considered in this report. Another major characteristic of these forests is the species that compose them. The species in the type are indicated by the approximate percentage of total volume of growing stock accounted for by each species. By this criterion, species and species groups are rated in table 1. More than three-fourths of the volume is in hardwoods. Pines make up about 6 percent and cypress about 16 percent of the volume.

Table 1.--Proportions of wetland hardwood growing stock in species groups, and relative contributions of species to the volume of growing stock

Group name	Proportion of growing stock	Common name of species[1]	Relative contribution to growing stock
	Percent		
Hardwoods with soft textured wood	57	Swamp tupelo	High
		Water tupelo	Medium
		Ogeechee tupelo	Minor
		Sweetgum	High
		Red maple	Medium
		Silver maple	Medium
		Yellow-poplar	Low
		Southern magnolia	Low
		Sweetbay	Minor
		American sycamore	Minor
		Eastern cottonwood	Minor
		American elm	Medium
		Florida elm	Minor
		Slippery elm	Minor

Table 1.--Proportions of wetland hardwood growing stock in species groups, and relative contributions of species to the volume of growing stock (continued)

Group name	Proportion of growing stock	Common name of species[1]	Relative contribution to growing stock
	Percent		
Hardwoods with hard textured wood	21	Water oak	High
		Willow oak	High
		Laurel oak	High
		Shumard oak	Medium
		Cherrybark oak	Low
		Overcup oak	Low
		Swamp chestnut oak	Low
		Green ash	High
		White ash	Medium
		Bitternut hickory	Medium
		Shagbark hickory	Low
		Mockernut hickory	Low
		Water hickory	Low
Cypress	16	Bald cypress	High
		Pond cypress	Medium
		Atlantic white-cedar	Minor
Pines	6	Loblolly pine	Minor
Total	100	Pond pine	Minor
		Slash pine	Minor
		Spruce pine	Minor

[1] Common name from Fowells (7).

Soft-textured hardwoods, primarily the tupelos, sweetgum, and soft maple, account for more than half the growing-stock volume. The most important hard-textured hardwoods are water oak, willow oak, laurel oak, and ash.

The array of species in table 1 does not indicate how the species are grouped in the various forest communities. These forests include pure stands of cypress and cypress in mixture with ash, elm, the oaks, the hickories, and the tupelos. Sweetbay, southern magnolia, yellow-poplar, sycamore, Atlantic white-cedar, and cottonwood make up a small portion of the volume. Data are not available to show the species composition of the communities or to develop a practical classification of the communities. Yet, the potential for timber production, as for other forest benefits, and the management of these forests require a practical system of classification as a basis for decisions and actions.

Figure 1 shows the locations of Forest Survey plots classified as wetland hardwoods in the Southeast. The distribution of these plots is very similar to the distribution of natural wetlands as indicated in the Water Atlas of the United States (8). Most of the plots occur in the Coastal Plain (3). Long strings and clusters of plots indicate stream margins and swamp areas. No dots are shown for areas reserved from timber production, such as the Everglades National Park and the reserved part of the Okefenokee Swamp. On figure 1, we have drawn lines on county boundaries to indicate the northwestern and the southern limits of the area with high potential for production of wetland hardwood timber.

Changes in water relations of stream margins, bays, wet pocosins, and similar topographic situations affect the species composition and growth of wetland hardwoods. Management actions which change the frequency of movement and depth of surface and ground water can either increase or decrease the growth of existing species, change the composition of existing forests, and affect the regeneration of the next stand (1, 9, 13, 14, 15, 19). From our survey of the literature it is apparent that knowledge is inadequate to accurately predict improvements in timber production of the wetland forest to particular changes in water relations.

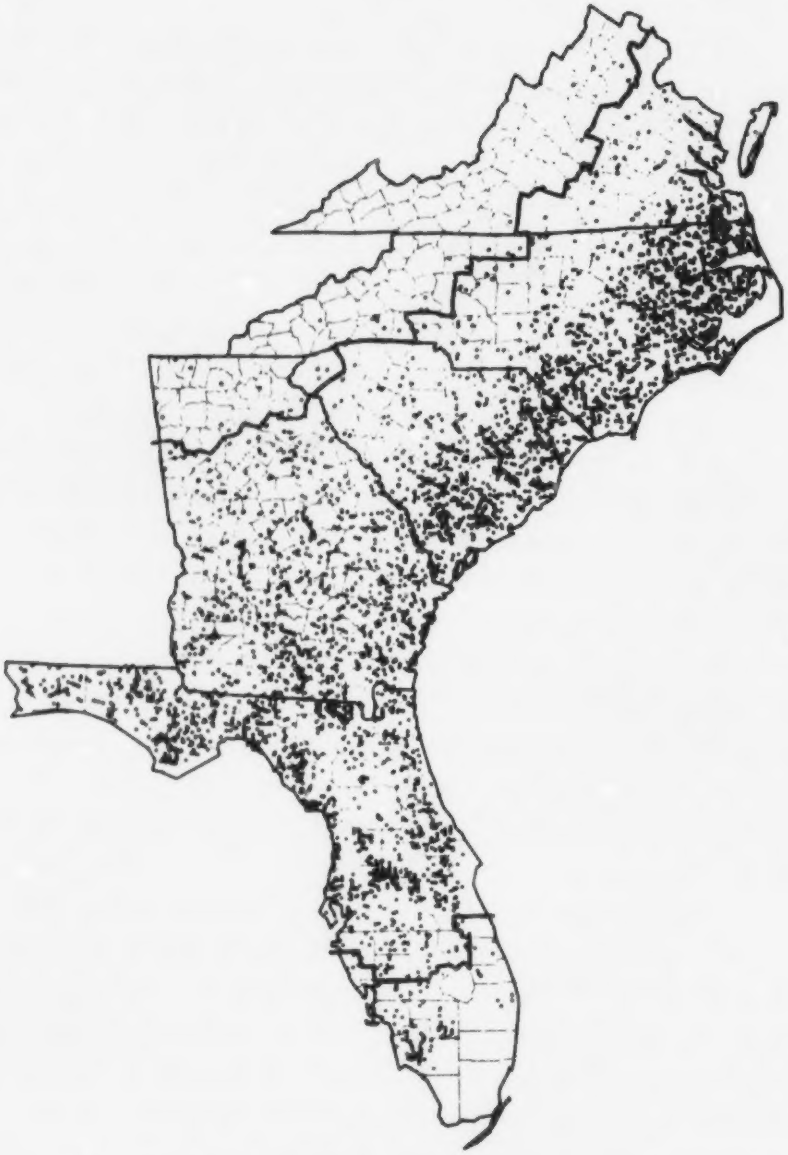

Figure 1.--The location of Forest Survey plots classified as wetland hardwoods in Virginia, North Carolina, South Carolina, Georgia, and Florida.

Commercial Forest Area

The amount of commercial forest land in the area outlined in figure 1 and the amount in wetland hardwood forests are shown by States in table 2. More than 12 million acres of commercial forest land are classified as wetland hardwood. In comparison to other forest types in the Southeast, the wetland hardwoods are exceeded in area only by the oak-hickory forest type with 23 million acres, the oak-pine type with 14 million acres, and the loblolly pine type with 12½ million acres. More than 57 percent of the wetland forests are in Georgia and Florida and 40 percent are in North Carolina and South Carolina. Relatively little wetland forest is in Virginia.

Table 2. --Commercial forest land in the area shown in figure 1 and area in wetland hardwoods, by State

States	Total area of commercial forest land	Area in wetland hardwoods
	- - - - Thousand acres - - - -	
Virginia	7,212	336
North Carolina	14,125	2,706
South Carolina	11,857	2,090
Georgia	21,517	3,154
Florida	15,306	3,732
Total	70,017	12,018

Physiographic Classes

The area of wetland hardwoods by physiographic classes and states is shown in table 3. These physiographic classes are defined as:

Table 3.--Area of wetland hardwoods by physiographic classes and states

States	All classes	Physiographic classes				
		Stream margins	Swamps, bays, and wet pocosins	Flatwoods and dry pocosins	Cypress ponds and channels	Rolling uplands
	- - - - - -	- - - - - -	- - - Thousand acres	- - -	- - - - - -	- - - - - -
Virginia	336	139	62	89	42	4
North Carolina	2,706	1,267	790	640	10	-
South Carolina	2,090	956	589	408	134	3
Georgia	3,154	2,358	322	117	324	33
Florida	3,732	1,076	1,079	534	1,005	37
Total	12,018	5,796	2,842	1,788	1,515	77

Stream margins:

Flood plains normally well drained but flooded during overflow of the streams.

Swamps, bays, wet pocosins:

Large, poorly drained depressions, often flooded for long periods and usually with peat soils and boggy conditions.

Flatwoods and dry pocosins:

Large, relatively level areas usually with sandy soils, very wet in the winter, and dry from late spring to fall.

Cypress ponds and channels:

Depressions filled with water most of the year, distinctly fluctuating water table.

Rolling uplands:

Large, well drained, undulating areas between major streams.

Almost half of the wetland hardwoods, about 5.8 million acres, are along stream margins. More than 2.8 million acres are in swamps, bays, and wet pocosins of the Coastal Plain. About 1.8 million acres are in the flatwoods and dry pocosins. These latter stands are mainly in low depressions, swales, and areas that do not drain quickly after rains. More than 1.5 million acres are in cypress ponds and channels. The small drains and depressions in the rolling uplands are a relatively small part of the wetland hardwoods.

Growth, Removals, and Mortality

Each Forest Survey plot is placed in a site class, which for wetland hardwoods is based on estimated capability of growing sweetgum timber (18). Although such estimates are available, they are not reported here. Wetland hardwoods are a mixture of many species and conditions, and these estimates of site classes are often unreliable. More reliable site class estimates cannot be made until growth and yield functions are developed for all species and sites. For these forests we can give reliable measures of actual growth, removals, and mortality.

Growing stock and net growth, removals, and mortality as percentages of growing stock for the wetland hardwoods are shown by States in table 4. Wetland hardwood forests contain more than 17 billion cubic feet of growing stock, which is 21 percent of all growing stock volume in the Southeast. Average volume of growing stock per acre in this type varies from 1,219 cubic feet for Florida to 1,739 cubic feet for South Carolina. The average volume per acre for all of the wetland forests is 1,426 cubic feet. This volume is higher than for any other forest type in the Southeast.

Table 4.--Wetland hardwood growing stock and net growth, removals, and mortality as percentages of growing stock, by State

State	Growing stock	Net growth	Removals	Mortality
	Million cu. ft.	Percent	Percent	Percent
Virginia	536	3.0	1.1	0.8
North Carolina	3,797	3.1	3.0	1.0
South Carolina	3,635	3.2	2.7	0.6
Georgia	4,617	3.3	2.7	0.8
Florida	4,551	2.8	1.6	0.7
Total	17,136	3.1	2.4	0.8

Net annual growth expressed as a percentage of the growing stock is only 3.1 percent compared with 5 percent for all forest types in the Southeast. Removals are 2.4 percent compared with 3.6 percent for all forest types in the Southeast. Mortality averages 0.8 percent compared with 0.6 percent for all forest types in the Southeast. These percentages can be changed to cubic feet and examined as average change per acre per year:

	Cubic feet
Growing stock per acre	1,426
Gross growth per acre/year	55
Mortality	11
Net growth	44
Removals	34
Net addition to the growing stock per acre/year	10

These data suggest opportunities for increased timber harvest and growth. It is reasonable to assume that net growth could be increased considerably through cultural practices to increase gross growth and reduce mortality.

One major limitation to development of appropriate action and research programs is the lack of a reliable system for classification of the forest communities of the wetland hardwoods. These forests are an aggregation of different forest communities, each varying in species composition and in growth with water relations, climates, and soils (1, 10, 11, 19). A good classification system is essential for the selection of cultural practices for desired responses.

Southeastern North Carolina

A recently surveyed area in southeastern North Carolina was examined in detail to relate timber production to stand composition, density, age, and physiographic class. In 1973, Forest Survey completed its fourth inventory of the Southern Coastal Plain of North Carolina. Commercial forests occupy almost 5.4 million acres, or 64 percent of the land area (5). Although this area is part of the South's pine timber basket, hardwoods make up 47 percent of the timber inventory, account for 37 percent of the timber growth, and provide 29 percent of the timber removals. Wetland hardwoods occupy about one out of every five acres classified as commercial forest. The tupelos, sweetgum, and wetland oaks are the most prevalent hardwoods on wetland sites.

Wetland hardwood plots established in 1962 and remeasured in 1973 were selected for detail analysis if they (1) occurred along stream margins, small drains or within deep swamps, (2) were dominated singly by tupelo, sweetgum, or wetland oaks, and (3) were undisturbed by man in the 11 years between surveys. Altogether, 138 sample plots met these criteria.

Volume of all live timber in trees 5.0 inches and larger in diameter at breast height on these sites averages 2,211 cubic feet per acre. Volume ranges from 1,875 cubic feet where wetland oaks predominate to 2,591 cubic feet where tupelo predominates (table 5).

Table 5.--Average volume per acre, annual growth rate, and mortality rate, by predominant species, on undisturbed wetland hardwood sites in southeastern North Carolina

Predominant species	Volume		Mortality	Net growth
	Growing stock	All live timber		
	- - Cubic feet - -		Percent of all live timber	
Tupelo	2,189	2,591	0.6	1.6
Sweetgum	1,593	1,915	0.4	3.1
Wetland oaks	1,535	1,875	0.5	1.8
All species	1,849	2,211	0.5	2.1

Across all of the sites, more than 80 percent of the volume is in trees which qualify as growing stock. If only the growing stock is considered, volume per acre still averages 1,849 cubic feet per acre.

Net annual growth of all live timber on undisturbed wetland hardwood sites averages 46 cubic feet per acre, but varies from 28 cubic feet on sites with less than 80 square feet of basal area per acre to 53 cubic feet for sites with more than 120 square feet of basal area (table 6). Since age of tupelo and sweetgum is difficult to determine from increment cores, correlation analyses with age are not reliable We chose instead to work with 10-year age classes. Across all of the density classes, growth is the highest in stands 40 to 60 years of age. Growth peaked at age 40 to 50 for basal areas of 80 to 120 square feet. More definitive studies are needed to verify or correct these apparent relationships.

Table 6.--Average annual net growth per acre, by density class and stand age, on undisturbed wetland hardwood sites in southeastern North Carolina

Density class (Basal area per acre)	All ages	Stand age (years)			
		Less than 40	40 to 50	50 to 60	More than 60
Square feet	- - - - - -	Cubic feet of all live timber	- - - - - -		
Less than 80	28	25	31	31	32
80 to 100	43	55	60	52	30
100 to 120	51	36	82	74	41
More than 120	53	--	64	72	44
All classes	46	38	57	60	40

Average net annual growth between surveys across all physiographic classes ranges from 33 cubic feet per acre where wetland oaks predominate to 59 cubic feet where sweetgum predominates (table 7). Tupelo grew best in deep swamps. Sweetgum appears to be most tolerant of differing soils and soil-moisture conditions and grew best in small drains or broad stream margins. Wetland oaks grew best on the well-drained narrow stream margins.

Table 7.--Average annual net growth per acre, by predominant species and physiographic class, on undisturbed wetland hardwood sites in southeastern North Carolina

Predominant species	All classes	Physiographic class			
		Narrow stream margins	Broad stream margins	Deep swamps	Small drains
	------ Cubic feet of all live timber ------				
Tupelo	41	41	33	49	39
Sweetgum	59	57	64	48	65
Wetland oaks	33	44	25	34	24
All species	46	49	42	47	45

We found no growth and yield functions or tables in the literature that could be applied to these forests. In the absence of such information, growth potentials were estimated by examining plots with above-average growth. Plots with growth in the highest 10 percent of the total were selected and a few with extremely high growth were excluded as unrepresentative. After selection we found that these plots were fully stocked and ranged in age from 50 to 60 years.

These upper-10 plots were growing 73 cubic feet per acre per year (table 8), which is 66 percent above the average of 44 cubic feet for the entire wetland forests. An examination of tables 7 and 8 suggests that these plots contain a high proportion of tupelo and sweetgum. Tupelo is growing faster on poorly drained deep swamps and small drains than on the well-drained stream margins. Studies have shown that tupelo seedlings grow faster in surface-flooded, moving water than in stagnant water or on well-drained moist soils (6, 10, 11, 12).

Table 8.--Average net annual growth per acre on the upper-10 plots by predominant species and physiographic class, on undisturbed wetland hardwood sites in southeastern North Carolina

Predominant species	All classes	Physiographic class: Narrow stream margins	Broad stream margins	Deep swamps	Small drains
	Cubic feet of all live timber				
Tupelo	79	44	59	100	93
Sweetgum	93	104	85	66	102
Wetland oaks	41	65	37	42	41
All species	73	80	60	77	72

On these upper-10 plots (table 8) sweetgum grew considerably faster than on all the sample plots (table 7). On narrow stream margins and small drains, growth is higher than 100 cubic feet per acre per year. Growth of wetland oaks does not vary as much by site as growth of tupelo and sweetgum. Research is needed to more reliably relate age, site, stocking and species to growth. Despite these limitations, the information obtained is important. Timber production on 10 percent of the area is at least 70 cubic feet per acre per year without culture. It is likely that growth for all the wetland hardwoods can be considerably increased with regulation of water, control of species composition, and other cultural practices.

Gaps in Knowledge

From our analysis of Forest Survey data and our review of the literature, we recognize three major gaps in knowledge: classification of forest communities, growth and yield functions, and responses to management actions.

Classification of Forest Communities

The term wetland hardwoods includes a mixture of hardwood forest communities. Wetland hardwoods occur in varying combinations as influenced by surface and soil water and management actions. An examination of the species composition of Forest Survey plots indicates that very few really fit forest cover types – 91 through 104 described in Forest Cover Types of North America (18). The species composition does not fit descriptions by Braun (3). Stubbs (19) grouped these forest communities under mixed bottomland hardwoods and tupelo-cypress swamps. Without an adequate method of classification of these wetland forest communities, it is very difficult to study, much less predict, responses to management practices.

Growth and Yield Functions

We found one set of site index curves and limited yield tables for species in this area (1, 2, 21). None of these growth functions are considered reliable for the wetland hardwood communities described in this report. The Forest Survey has developed its own site quality classifications, based on limited data (21); but these are inadequate for estimating potential timber growth. Applequist (1) published site index curves and yield tables for tupelo stands in Georgia. His stands were specially selected, well stocked and apparently even aged. An examination of Applequist's data in relation to Forest Survey plots suggests that his site curves and yield tables cannot be applied to very many tupelo stands in wetland hardwood forests. Reading of the Proceedings of the 1966 Symposium on Hardwoods of the Piedmont and Coastal Plain (9) leads to an important observation. References on growth and yield functions and on site index curves are lacking for bottomland hardwoods. Growth and yield are being studied by the North Carolina State University Hardwood Research Cooperative, but results have not yet been published.

Responses to Management Actions

An annotated bibliography of southern hardwoods reveals very few reports based on experimental evidence (17). Observations such as those of Applequist's (1, 2), Maki's (15), and Broadfoot's (4) suggest opportunities to control growth and reproduction through water regulation. Research is needed to discover ways to regulate stand density and water, control species composition, regenerate stands, improve genotypes, and apply nutrients. Such findings would provide a basis for scientific management of wetland hardwood timber.

Summary

In the wetland hardwood forests of Virginia, North Carolina, South Carolina, Georgia, and Florida, the dominant species are tupelos, sweetgum, the wetland oaks, cypress, ash, and soft maple. Fifty-seven percent of the growing stock is in soft-textured hardwoods. Almost half of these forests occur on stream margins and about one-fourth are in swamps, bays, and wet pocosins. The remainder are in flatwoods, dry pocosins, cypress ponds, channels, and rolling uplands.

The 12 million acres of wetland forests contain 21 percent of the total growing stock in the Southeast. Growth and removals are lower and mortality is higher than for the other forest types in the Southeast. An analysis of a recently surveyed area in southeastern North Carolina suggests a potential average growth of at least 70 cubic feet per acre per year on 10 percent of the area without culture. It is likely that growth for all the wetland hardwoods can be considerably increased with regulation of water, control of species composition, and other cultural practices.

Significant gaps in our knowledge must be filled if we are to make wise decisions for the protection and use of these forests. A more useful classification of wetland hardwood communities must be developed. Growth and yield functions must be prepared for the forest communities. Ways must be found to predict responses of the forest to a number of management actions, especially water regulation, species changes, regulation of stand density, and fertilization.

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Chapter 10

INTENSIVE MANAGEMENT OF WATER FOR FISH PRODUCTION

R.O. Smitherman and C.E. Boyd

Abstract

Fish production in warmwaters of the Southeastern United States has been increased from approximately 100 pounds per acre in natural waters to 20,000 pounds per acre with intensive culture systems using artificial circulation, filtration and supplemental feeding. Intensification of fish production results in alterations of water quality. Changes in factors of importance to health and growth of aquatic organisms include phosphorus, organic and inorganic nitrogen, BOD and COD. Methods by which detrimental changes in water quality parameters have been combatted involve mechanical aeration, polyculture with secondary fish species to consume waste feeds and detritus, aquatic plants to absorb nutrients and prevent excessive phytoplankton blooms, and recirculation and filtration of water to minimize BOD and COD.

Introduction

Development of high-intensity culture of fish has lagged considerably behind that of land animals such as cattle and poultry partially because aquatic organisms live in an environment foreign to man, and consequently one which is poorly understood. Fortunately, much methodology can be adapted from the several animal sciences in agriculture, but special problems arise because fish are poikilotherms. Temperature, interrelated in a complex way with water quality, photoperiod, food supply, and space influence growth rate, reproduction, and susceptibility to diseases.

Intensive cultures of fish, with populations much more dense than in nature, create unique problems, among them nutritional inadequacies, facility of disease transmission, and increased oxygen demand arising from metabolism of the biota and from feeding wastes.

Research over the past 40 years at the Agricultural Experiment Station has been oriented toward producing ever higher yields of fish and other aquatic organisms, and problem-solving in areas presenting constraints to the development of aquacultural industries.

Fish Production at Various Levels of Culture

Fish production in natural waters is dependent upon fertility of soils of the watershed (33). This production, expressed as standing crop of fish, has been reported at levels of 24-482 pounds per acre in Alabama streams (26) and 47-125 pounds per acre in unfertilized ponds in the Piedmont region of Alabama (21,

When fertility of water was artificially increased by additions of inorganic nutrients standing crop of bluegill (*Lepomis macrochirus* Rafinesque) was raised as high as 588 pounds per acre (21). Combinations of bluegill and largemouth bass (*Micropterus salmoides* Lacepede) in ponds receiving organic and inorganic fertilizers yielded up to 437 pounds per acre (25). Other species, buffalofish (*Ictiobus* spp.) and *Tilapia* spp., which feed directly on plankton, produced 1,000-1,500 pounds per acre in fertilized ponds (29).

Fish production is further increased by supplemental feeding, and various forms of aeration. The following yields have been realized at Auburn University using various experimental systems of culture:

Species	Culture System	Standing crop (lb /A)	Duration (months)	Author
Bluegill-Bass	Pond	1,129	42	Schmittou (19)
Tilapia	Pond	1,795–4,380	6	Swingle (23)
Channel catfish	Cages in pond	2,007	5	Schmittou (20)
Channel catfish	Pond/water hyacinths	2,720	6	Lovshin (14)
Channel catfish	Pond	3,412	7	Prather and Lovell (18)
White catfish (_Ictalurus catus_ L.)	Pond/aeration	6,600	7	Loyacano and Jeffrey (15)
Channel catfish Tilapia	Pond/aeration	5,000 catfish 2,000 tilapia	6	Smith (22)
Channel catfish	Concrete ponds/ filtration and circulation	20,000	7	Greene (9)

Effects of Various Management Procedures on Water Quality

Water Chemistry

The chemical environment influences fish survival and production in ponds. The more common problems with water chemistry involve dissolved oxygen, carbon dioxide, pH, ammonia, and hydrogen sulfide. Most problems in water quality are related to low concentrations of dissolved oxygen. Requirements of dissolved oxygen for warm water pond fishes were summarized by Moss and Scott (17). Minimal oxygen levels for survival of bluegill, largemouth bass and channel catfish were approximately 1 mg/l. For health and optimum growth, fish culturists feel that oxygen should not drop below about 2-5 mg/l.

Carbon dioxide concentrations usually are inversely related to those of dissolved oxygen in pond waters. Ellis (7) indicates that most waters used for fish culture contain less than 4 mg/l carbon dioxide. However, concentrations up to 20-30 mg/l can be tolerated by fish provided oxygen is near saturation. At low levels of dissolved oxygen, toxicity of carbon dioxide increases.

Toxicity to pond fish from hydroxide ion concentration occurs below pH 4.0 and above pH 11.0. However, if pH values remain above 9.5 or below 6.0 for extended periods, fish will not grow well even though they may survive. Mineral acidity from acid mine drainage is usually responsible for pH values below 5, while waters with high concentrations of organic matter may be in the pH range of 5 to 6. Liming agents may be used to improve low pH. High pH conditions may sometimes be alleviated by use of acid-forming fertilizers such as ammonium nitrate or ammonium sulfate (27).

Ammonia concentrations above 1 mg/l as determined by the nesslerization procedure, generally indicate organic pollution. Un-ionized ammonia is detrimental or lethal to fish at concentraions of approximately 2.5 mg/l (8). Such conditions are relatively rare since the percentage of un-ionized ammonia is low within normal pH ranges of natural waters. At 25°C, the percentages of un-ionized ammonia are as follows: pH 7 - 0.7%; pH 7.5 - 1.73%; pH 8 - 5.28% ; pH 8.5 - 14.97%; pH 9 - 35.76% (34). For example, a water sample containing 5 mg/l of ammonia at pH 8.5 would contain only 0.75 mg/l un-ionized ammonia, and would not cause toxicity to fish.

Hydrogen sulfide has been implicated as the cause of death in fish exhibiting the unusual clinical sign of chocolate-colored blood.[1] Bonn and Follis (1) reported cases of hydrogen sulfide toxicity to catfish in ponds of northeast Texas. A LD_{50} of 1.4 mg/l of un-ionized hydrogen sulfide at pH 7 was recorded for adult channel catfish. The toxicity of hydrogen sulfide increases with decreasing pH. Most cases of alleged toxicity of hydrogen sulfide to fish were not substantiated by measurements of either pH or sulfides.

Fertilization

Natural waters in the southeastern United States generally contain low concentrations of nutrients and are unproductive of phytoplankton and fish. These waters may be classified as (i) those transparent waters which generally contain abundant growths of submersed plants, (ii) those turbid with suspended soil particles, and (iii) those stained with humic substances. Monthly applications of inorganic fertilizers at the rates of 40 lb /A of 20-20-5 will stimulate the production of microscopic plants. In ponds which have waters of low alkalinity (0 to 20 mg/l as $CaCO_3$) and acid bottom muds (pH less than 6), applications of 1 to 3 tons of agricultural limestone must be made before the pond will respond to fertilization. (32, 36).

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[1] Allison, R. 1973. Personal communication.

The turbidity resulting from phytoplankton growth usually restricts light penetration to approximately 2 feet and essentially eliminates submersed aquatic macrophytes through shading.

Phytoplankton communities usually consist primarily of one or two species (2), whose numbers may fluctuate drastically in a relatively short period of time. Sudden decline in a species may greatly reduce the rate of oxygen production and in some cases result in fish mortality. Applications of superphosphate have been used to shorten the time of recovery to optimum phytoplankton density (30).

Collodial particles of muddy waters precipitate following stimulation of phytoplankton growth by inorganic fertilization (25). If clearing of waters is not effected by inorganic fertilizers, 1 ton per acre of organic matter, such as cottonseed meal, hay or animal manure, may be applied (12).

Waters stained by humic substances may be made transparent by liming preparatory to fertilization. Excellent accounts of clearing brown-stained waters by liming are given by Hasler, Brynildson, and Helm (10).

Excessive applications of inorganic fertilizers and accumulation of organic matter in old ponds may cause over-production of phytoplankton, especially the blue-greens, Cyanophyta,which causes shallow stratification. Overturns caused by cooling of surface waters by rains or by cool weather, and upwelling of oxygen-deficient waters caused by strong winds may lead to oxygen depletions and fish kills (30). Methods for prevention of fish kills include thinning of phytoplankton by adding 0.75 lb of copper sulfate per surface acre (6) and recirculation and agitation of pond waters to effect re-oxygenation (30).

Water Quality and its Improvement in Intensive Fish Cultures

Highest production of fish is attained through use of supplemental feeding, and the maximum attainable levels are regulated by the ability of the culture system to oxidize its wastes and maintain sufficient dissolved oxygen for fish growth and survival. An example of the wastes contributed to the waters of an intensive culture system by feeding can be illustrated for a 1-acre earthen pond which receives 3,000 pounds of fish feed during a 180-day growing season and yields 2,500 pounds of catfish:

Constituent added	% dry wt.		lb dry wt.		Feed not converted to fish (lb)
	Feed	fish	Feed	fish	
Dry matter	95	20	2,850	500	2,350
Nitrogen	6	12	171	60	111
Phosphorus	1	3	28	15	13

These wastes enter the water as a variety of substances, including carbon dioxide, ammonia, and undigested organic compounds and minerals. The organic consitutents create a considerable oxygen demand, and reduce the amount of oxygen available to the fish and other biota of the system. Inorganic nutrients, particularly nitrogen and phosphorus, which are contributed by the wastes cause dense phytoplankton growth and increase zooplankton production. Rates of primary productivity in catfish ponds receiving about 3,000 pounds of feed per acre averaged 5.32 g/m^2 of organic matter, or 8,500 pounds per acre during a 180-day growing season. The amount of organic matter produced by photosynthesis was about 4 times that contributed directly by the feeding wastes (3).

The biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) of nine fish ponds which received applications of fish feeds gradually increased with feeding rates. Maximum 5-day BOD values ranged from 8-10 mg/l and COD values from 30-80 mg/l (4). There was a corresponding increase in phytoplankton densities, indicating that the increases in BOD and COD were related to increases in phytoplankton growth rather than simply to wastes. This contention was verified when BOD and COD declined with decreased phytoplankton in the fall, even though feeding rates remained at maximum (40 pounds per acre per day). It should not be interpreted from these data that blooms of phytoplankton are undesirable in intensive culture systems. Except for systems which receive artificial aeration, photosynthesis must evolve sufficient oxygen to meet the oxygen requirements of the biota. Furthermore, failure to maintain turbidity will encourage growth of nuisance submersed weeds. However, the life cycle of phytoplankton is usually 1 to 2 weeks, and upon death and decay these plankters add to the oxygen demand. Quite often, off-flavors described as "earthy-musty" are detected in intensively cultured fish (13). These off-flavors have been attributed to blooms of blue-green phytoplankton and/or actinomycetes growing on detritus of the pond bottom. Efforts must be made to prevent excessive phytoplankton production and its attendant problems. Since herbicides other than copper compounds are not cleared by the FDA for use with food fish, other means of regulating phytoplankton production and supplying additional oxygen have been investigated.

Mechanical aeration. Using air blowers which released 150 cubic feet per acre per minute, Loyacano and Jeffrey (15) increased production of white catfish to 6,600 pounds per acre. Not only did this practice increase concentrations of oxygen to saturation, turbulence maintained a suspension of fine soil particles which restricted light penetration and phytoplankton production. Aeration at less than 150 cfm has been used to prevent stratification in larger ponds, but the economic feasibility is not known.

Polyculture. Smith (22) used Tilapia aurea in combination with channel catfish as agents to consume fine waste particles of feed offered the catfish, and as biofilters to control phytoplankton populations. Some of the young tilapia were also consumed by catfish. This was effective and oxygen demand in earthen ponds was reduced so that feed rates could safely be increased from 35 to 70 pounds per acre per day. Maximum yields of catfish were about 5,000 pounds per acre, with an additional 2,000 pounds of Tilapia aurea.

Water hyacinths [Eichhornia crassipes (Mart) Solms]. These floating plants will remove nutrients from the water and reduce phytoplankton production. In recent studies at Auburn University, water hyacinths were stocked in earthen ponds at rates of 0, 5, 10, and 25% of surface area. All ponds received applications of nitrogen and phosphorus. The competition between water hyacinths and phytoplankton can be illustrated by the following [2].

% Coverage by water hyacinths	Phytoplankton/ml
0	29,000
5	13,000
10	4,000
25	3,000

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[2] McVea, C. and C. E. Boyd. 1973. Unpublished data.

Recirculating biofilters. Biological methods similar to those utilized by municipal waste treatment facilities have been experimentally incorporated into fish production systems in an effort to clean and reuse water in intensive fish culture. Production up to 20,000 pounds per acre has been achieved in .005-acre ponds (9). However, costs of production of operation presently prohibit commercial use.

Raceways. In an effort to reuse water in fish culture, earthen raceways are employed as production units for channel catfish and rainbow trout, *Salmo gairdneri* Richardson (5). Water flows from a storage basin through the raceway to a settling basin where solids precipitate; subsequently, water from the upper levels of the basin is pumped back to the storage basin at the head of the raceway. Yields of up to 40,000 pounds per year per acre of raceway surface have been reported. The system contains additional acreage in the settling and storage basin. Preliminary estimates indicate that catfish production costs are similar to those of pond culture. Due to accumulation of wastes and consumption of oxygen, growth of fish decreases from upper to lower sections of the raceway system.[3]

Effluents from Warmwater Fish Culture

Hinshaw (11) expressed concern with the pollutional load of waters released from fish hatcheries and fish farms. To date, there has been no attempt to regulate the discharge of effluents from fish cultural activities. The following data from nine catfish ponds at Auburn University show some alteration in water quality, particularly increased levels of alkalinity, hardness, BOD, COD, and nitrogen compounds.

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[3] Hill, T. 1973. Personal communication.

Water Quality Parameter	Before culture (April) mg/l	At harvest (October) mg/l
pH	7.1	7.2
Total alkalinity	19	34
Total hardness	14	24
Soluble inorganic phosphorus	0.017	0.006
Total phosphorus	0.054	0.074
Nitrate	0.087	0.114
Ammonia	0.04	0.52
Kjeldahl nitrogen	0.60	1.43
BOD	1.27	3.51
COD	13.60	36.11

Unless the volume of effluent was great in relation to the volume of receiving water, it appears there would be little ecological change effected by discharge from these ponds.

Research Needs

The research priorities for intensive fish culture as developed by fisheries technicians throughout the Southeastern United States have been reviewed by Smitherman (23), and Smitherman and Corley (24). Primary effort should be directed to the improvement of water quality and toward maximum production of fish per unit of water. Several means through which this might be accomplished include: (i) development of concentrated feeds which are more completely converted to fish tissue (18), (ii) refinement of polyculture techniques to fully utilize waste feed and natural foods not used by primary culture species (35), and (iii) genetic modification of fish stocks for improved growth, food conversion and disease resistance (16).

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Chapter 11

THE DISCHARGE OF TREATED WASTEWATERS AND ITS EFFECTS ON FISH, GAME, AND WILDLIFE

Broughton A. Caldwell

ABSTRACT

Fish, game, and wildlife encompass a multitude of organisms that are affected by wastewater discharges. Definitions of these terms and others such as pollution were given to aid in establishing and understanding effects by wastewaters. Fishes and benthic macroinvertebrates are usually subjected to the greatest direct impact of wastewaters. Changes in types of species and total numbers are typical responses to the introduction of wastewaters. Biological blooms of "nusiance" organisms resulting from wastewater influence may indirectly affect stream populations. Effects of toxic, sometimes lethal materials, such as silt, acids, elevated and depressed temperatures, and organic materials are discussed. Effects of wastewaters on stream populations may be demonstrated by the use of diversity indexes.

THE DISCHARGE OF TREATED WASTEWATERS AND ITS EFFECTS ON FISH, GAME, AND WILDLIFE

Broughton A. Caldwell

INTRODUCTION

The entry of wastewaters into our streams, lakes, and rivers affects physical, chemical, and biological characteristics in downstream waters. Today the trend toward protecting and preserving our natural environment has placed increased emphasis on effective water quality management and wastewater treatment. The actions of wastewaters on fish and wildlife associated with a receiving water body are often subtle and complex. The most widely discussed effect is that which occurs when large amounts of putrescible organic material are involved. Non-lethal inorganic substances, such as silt, are often as destructive to stream life as organic materials if large amounts are involved. Toxic chemicals, radioactive materials, and other factors such as temperature also exert their effects.

Definitions are used freely in this paper to aid in clarification.

COMMENTS CONCERNING FISH, GAME AND WILDLIFE AND DISCUSSION OF IMPORTANT TERMS

I am associated with the Environmental Protection Division, Georgia Department of Natural Resources (the Environmental Protection Division under governmental reorganization of 1972 assumed responsibilities of the Georgia Water Quality Control Board) and I am familiar with wastewaters and their effects on fish, game, and wildlife in Georgia. Thus, this paper will address itself frequently to the discharge of wastewaters and its effect on fish, game, and wildlife in Georgia.

The discharge of all wastewaters in Georgia is regulated by the Georgia Water Quality Control Act of 1964 as amended. Based upon this law it is illegal to discharge untreated wastewaters. The Environmental Protection Division of the Georgia Department of Natural Resources (1) specifies in its rules that all sewage must receive no less than secondary biological treatment before discharge. Industrial and other wastes must also receive secondary biological treatment or its equivalent. Higher degrees of treatment may be prescribed as necessary.

According to the Federal Water Pollution Control Act Amendments of 1972, secondary treatment will be required nationwide by July 1, 1977. Although certain laws exist that presently require a minimum of secondary treatment, some wastewaters at present receive only primary treatment or none. This is true in Georgia as in other states but enforcement is actively pursued. Therefore, reference to wastewaters includes those properly treated, inadequately treated, and untreated.

In order to describe the effects of wastewaters on fish, game, and wildlife, each should be defined. Wildlife, especially, encompasses a broad spectrum of organisms.

According to Woolf (2) fish are any of the numerous cold-blooded strictly aquatic craniate vertebrates typically possessing an elongate spindle-like body terminating in a broad caudal fin, limbs in the form of fins when present, and a two chambered heart. Game is defined as animals under pursuit or taken in hunting, especially wild animals hunted for sport or food. Wildlife is defined as living things that are neither human nor domesticated, especially mammals, birds, and fishes hunted by man. These definitions are adhered to in this paper and wildlife is used in the broader sense, that of all living things (excluding plants, fish, and game) not human or domesticated. By this definition, wildlife includes many endemic aquatic organisms including immature aquatic insects, crustaceans, and gastropods. The effects to these aquatic organisms is directly related in many instances to game and other types of wildlife in the form of food webs.

The public is usually most concerned with wastewater discharges that cause "pollution" and endanger the plants and animals associated with water, especially ones of economic and aesthetic importance. The acceptance of a definition of water pollution is of paramount importance when considering effects of wastewaters. Pollution has been defined by Beck (3) as, "The alteration of any body of water, by man, to such a degree that said body of water loses any of its value as a natural resource." A legal definition of pollution, Georgia Legislature,(4) states that: "'Pollution", means any alteration of the physical, chemical, or biological properties of the waters of this State, including change of the temperature, taste, or odor of the waters, or the addition of any liquid, solid, radioactive, gaseous, or other substances to the waters or the removal of such substances from the waters, which will render or is likely to render the waters harmful to the public health, safety, or welfare, or harmful or substantially less useful for domestic, municipal, industrial, agricultural, recreational, or other lawful uses, or for animals, birds, or aquatic life."

For the purposes of this paper, water pollution means any impairment of the suitability of water for beneficial uses due to human influenced changes. As Warren (5) points out, pollution caused by man should be distinguished from "natural" pollution.

EFFECTS ON FISH, GAME, AND WILDLIFE

Wastewater discharges usually impose the greatest direct impact on fishes and other strictly aquatic organisms. Other life such as beavers, certain birds, and those types not in continual contact with an aqueous environment are less directly affected.

Many species of fish have narrow tolerance ranges concerning dissolved oxygen and temperature requirements and are intolerant of various factors such as toxic materials. A great deal more is known of the environmental requirements of many fish as opposed to other aquatic organisms, but for various reasons fishes have received less use as indicators of environmental conditions. Fish presence cannot be correlated with water quality in regard to wastewater discharges. However, the absence or extreme scarcity of some fishes or a population imbalance in a water body below a wastewater discharge and not above the discharge is a strong indication of an adverse effect due to the discharge. Massive or abrupt discharges of wastewaters may result in fish kills.

Benthic (bottom-dwelling) macroinvertebrates are sensitive to environmental stress as are fish and thus serve as useful indicators of effects of wastewater discharges. These benthic organisms are usually not highly vagile, have relatively long life spans in the aquatic environment, and are thus indicators of environmental conditions that have occurred in the recent past. Water quality can be correlated with presence or absence and population imbalances as for fishes.

It must be emphasized that any data concerning fish or other aquatic life populations cannot be fully meaningful unless life histories or ecology is known.

A recent report by the Georgia Water Quality Control Board (6) included fish population characteristics of the Flint River near the fall line and below Albany. Fishes below Albany were subjected to approximately 10 million gallons per day of primary treated domestic sewage from the city of Albany wastewater treatment facility and industrial wastewaters from several sources. The standing crop in the fall line area was estimated to be 56.2 pounds per acre with 45.0 pounds desirable species of harvestable size. A standing crop of 175.3 pounds of fish per acre was estimated in the area below Albany. Slightly more than 10 percent of this total were desirable species of harvestable size. The report stated: "These differences can be attributed to differences in habitat type, the influence of fall line on species distribution, and the effects of manmade alterations on the stream. The Albany section supports a higher standing crop than the fall line section but produces a lower poundage of harvestable size desirable fish. The higher standing crop in the Albany area can be attributed, in part, to the enrichment of the Albany section by domestic pollution. The relatively unpolluted fall line section evidently supports a lower standing crop of fish but produces a more diverse and desirable fishery."

An apparent difference in fish populations in major rivers below wastewater discharges from urban areas in Georgia was noted in a recent investigation of mercury pollution, Georgia Water Quality Control Board, (7). Rough fish were collected almost exclusively in urban areas below major wastewater discharges. Largemouth bass, Micropterous salmoides, were generally not collected in such areas.

Heavy organic pollution usually drastically reduces the number and variety of species present in a receiving stream. Moderate or light organic pollution, in some instances, may result in increased numbers of species. There may also be increases in species in the recovery zones of streams that are heavily polluted.

An example of how large volumes of treated and partially treated wastewater (chiefly organic) adversely affects populations of stream macroinvertebrates (low number of species, high number of individuals) is given in recent water quality monitoring data of the Environmental Protection Division, Georgia Department of Natural Resources (8) for the Chattahoochee River. Table 1 illustrates the macroinvertebrate community that occurred in the Chattachoochee River at Georgia Highway 92 near Atlanta in late 1973. The influence of wastewaters from the Atlanta area can readily be recognized when these data are compared to Table 2 which represents the macroinvertebrate community of the river near Franklin where some natural stream purification had occurred. Inorganic pollution in the form of silt deposits also affects the aquatic community of the Chattahoochee at Georgia Highway 92.

An example of enrichment of a stream with a subsequent large number of species present is the Savannah River in Georgia near Augusta. Environmental Protection Division, Georgia Department of Natural Resources, (8).

Table 1. Macroinvertebrate Populations of the Chattahoochee River at Georgia Highway 92, 1973[a]

ORDER[b]	COMMON NAME	SCIENTIFIC NAME[c]	AMBUNDANCE
DIPTHERA	FLY LARVAE	*Conchapelopia sp.*	2
		Psectrocladius sp. (larvae)	11
		(pupae)	1
		Chironomus sp.	5
		Goeldichironomus holoprasinus	3
OLIGOCHAETA	SEGMENTED WORMS		832
HIRUDINEA	LEECHES		55
BASOMMATOPHORA	SNAILS	*Physa sp.*	3
ACARI	MITES		1

[a] Compiled from Environmental Protection Division, Georgia Department of Natural Resources, 1973. Water quality monitoring data (in press).

[b] Oligochaetes and leeches not determined further than Class.

[c] Some organisms not determined further than Class or Order.

A total of 45 species of aquatic macroinvertebrates were present at a location downstream from wastewater sources at Augusta. Upstream from Augusta, a total of only 13 species was collected.

Direct effects on fish and wildlife in streams due to inorganic substances such as silt usually are subtle unless large amounts of material are involved. An effect may be that silt beds develop in streams and support growths of aquatic vascular plants. These growths may afford a combination of shelter and food for species occurring in the area. One of the most dramatic instances of adverse effects on stream life in Georgia due to siltation concerned discharge of impounded waters used for power generation on the Soquee River (Environmental Protection Division, Georgia

Table 2. Macroinvertebrate Populations of the Chattahoochee River at U. S. Highway 27, 1973[a]

ORDER	COMMON NAME	SCIENTIFIC NAME[c]	ABUNDANCE
EPHEMOROPTERA	MAYFLY NUMPHS	*Stenonema sp.*	33
		Tricorythodes sp.	88
TRICHOPTERA	CADDISFLY LARVAE	*Hydropsyche sp.*	75
ODONATA	DRAGONFLY NYMPHS		1
DIPTERA	FLY LARVAE	*Conchapelopia sp.*	1
		Ablabesmyia mallochi	5
		Ablabesmyia janta	5
		Rheocricotopus sp.	6
		ORTHOCLADIINAE (pupae)	3
		Cricotopus sp.	58
		Psectrocladius sp.	91
		Rheotanytarsus sp. (larvae)	235
		(pupae)	4
		Parachironomus pectinatellae	1
		Polypedilum sp.	49
		EMPIDIDAE (larvae)	3
		(pupae)	3
		Simulium sp.	7
ISOPODA	ISOPODS	*Asellus sp.*	2
AMPHIPODA	SCUDS	*Crangonyx sp.*	4
DECAPODA	CRAYFISHES	*Procambarus spiculifer*	7
OLIGOCHAETA	SEGMENTED WORMS		131
HIRUDINAE	LEECHES		5
BASOMMATOPHORA	SNAILS	*Ferrissia sp.*	3
		Physa sp.	2
ACARI	MITES		51

[a] Compiled from Environmental Protection Division, Georgia Department of Natural Resources, 1973. Water quality monitoring data (in press).

[b] Oligochaetes and leeches not determined further than Class.

[c] Some organisms not determined further than Class or Order.

Department of Natural Resources, water quality surveys files). In July, 1972 a reservoir used in generation of electrical power was flushed to reduce the silt load and to allow for penstock repairs. An investigation upstream only one species was collected, a crayfish, *Cambarus latimanus*. Silt deposits greater than 3 feet deep were measured. A fish kill was reported. Almost all microhabitats immediately below the discharge were rendered uninhabitable due to the flushing of silt and subsequent retention of flow in the river for an extended period during refilling.

Nutrients that include nitrates and phosphates present in wastewaters having received only secondary treatment may result in bloams of algae or fungi. The value of receiving waters for fishing and other beneficial uses may be seriously impared. Such bloams may also lead to taste and odor problems in water supplies.

In Georgia, Jackson Lake has been of major concern due to high nutrient levels and algal bloams. The reservoir receives a high input of nutrient rich wastewaters from the Atlanta metropolitan area. Dense algal bloams have occurred each summer for the past several years. To date the fishery of the lake has been excellent. The high concentration of algae are desirable for threadfin shad, *Dorosama petenense*, which is a principal food for predatory game fish. Excessive densities of algae are also capable of causing oxygen depletion resulting in fish kills.

A recent investigation of the Altamaha River, Environmental Protection Division, Georgia Department of Natural Resources,(9) revealed nusiance growths of algae and fungi below the discharge of a chemical-cellulose industry. Total phosphorous concentrations in one area of the river below the discharge reached a level considered critical for the development of nusiance algal growths. Excessive slime growths have been reported for many years in lengths of river downstream from the discharge. Shad fishermen have been vociferous and have claimed the growths adversely affect the taking of shad.

Recent work by Ahern (10) on Lake Sidney Lanier in Georgia concerned biological bloams in embayments of the lake which received wastewaters high in nitrates, nitrites, phosphates, and oxygen demanding organic materials. Both algal and amoebic bloams were monitored. The primary alga and amoeba of the bloams were considered as potential health hazards for man and animals.

Due to concern of nusiance and other conditions developing as a result of highly fertile wastewaters, the use of tertiary or advanced treatment has gained increased importance. Eckenfelder (11) includes suspended solids, biochemical oxygen demand (usually less than 10 to 15 mg/1), refractory organics, nitrogen, phosphorus, and inorganic salts as pollutants removed by tertiary treatment.

It is almost impossible to list the many types of toxic and potentially lethal materials which enter receiving waters. Many products and by-products of industry including acids, pesticides, and detergents enter streams intentionally and unintentionally. Okapilco Creek near Moultrie, Georgia has been known to be affected by acidic discharges related to fertilizer manufacture. A study in 1973 involving this stream (Environmental Protection Division, Georgia Department of Natural Resources, 12) revealed a serious impairment of water quality primarily due to low pH values below the discharge. Only one aquatic macroinvertebrate was present in the region found to be affected. On the date of the investigation the pH was 3.2.

Water pollution due to mercury (toxic and lethal effects) in certain industrial wastewaters and the damaging effects to the environment world-wide have received mounting concern in recent years. Industries which manufacture chlorine gas and caustic soda through the electrolysis of brine using mercury as on electrode have been cited by Selikoff (13) as significant contributors to mercury pollution (mercury converted to methylmercury by microorganisms is the toxic form). Investigations by Zeller and Finger (unpublished) and the Georgia Water Quality Control Board (7) have shown that mercury pollution by wastewater discharges of chlor-alkali industries has occurred in the southeastern United States and Georgia. The mercuric content of wastewaters discharged from chlor-alkali industries in Georgia has been reduced drastically since the problem has been identified (Environmental Protection Division, industrial waste service files).

Fishes appear to concentrate mercury in appreciable amounts yet show no lethal effects at concentrations well above maximum acceptable levels for human consumption. Reaction in birds and warm blooded animals living in areas of mercury pollution by wastewaters is pronounced, however. Odom (14) has reported that clapper rails, Rallus longirostrus waynei, near Brunswick, Georgia (site of a chlor-alkali plant) have been found to be affected by mercury poisoning. The diet of the clapper rail in food habit studies in Georgia consists largely of fiddler crabs, Uca sp., square back crabs, ?Albuncae sp., and periwinkel snails, Littorina sp. Results of sampling blue crabs, Callinectes sapidus, collected near a mercury discharge in an estuarine area by the Georgia Water Quality Control Board (7) has revealed high concentrations of mercury. Fiddler crabs have much the same feeding habits of blue crabs and would be expected to contain high levels of mercury also in areas where a mercury discharge occurs. Mercury poisoning in clapper rails, and other vertebrates in the Cape Fear area of North Carolina has been documented by the North Carolina Wildlife Resources Commission (unpublished).

The effects of heated effluents on life associated with water bodies, whether the discharges are treated or untreated, are usually referred to as thermal pollution. This definition is highly restrictive, though, since thermal in a broad sense refers to heat control. Low level discharges of hypolimnetic waters (cold) from large dams in power generation can indeed be thermal pollution as are heated discharges from steam generating facilities.

A report of the Georgia Water Quality Control Board (15) stated that very low diversity of species and low densities of individuals (macroinvertebrates) existed in a length of the Chattahoochee River below the dam of Lake Sidney Lanier. These conditions were due to release of nutrient-deficient cold water in intermittent power waves from the lower portions of Lake Lanier.

Since 1961 the Georgia Game and Fish Division has annually stocked trout in the first thirty miles of the river below the dam. An investigation by Welch (16) has demonstrated that the trout do not reproduce in this length of the river.

The study of total effects due to heated discharges on fish and other aquatic organisms has not been detailed. A study by Frey (unpublished) concerning a heated discharge to a large Georgia reservoir revealed a good winter fishery in the area of the discharge. In summer months, however, fish were found to avoid the discharge area. Gibbons (17) has studied the reproductive dynamics of yellow-bellied turtles, Pseudemys scripta, in

Par Pond, a reservoir receiving heated effluent from the Savannah River Plant at Aiken, South Carolina. These turtles reached exceedingly large body sizes and exhibited extraordinary juvenile growth rates when compared with turtles of this species from other populations in the vicinity. Diet differences resulting from increased productivity at lower trophic levels due to the heated effluent were considered to be a major factor in these phenamena.

Radioactive materials associated with wastewaters are similar in harmful effects to toxic substances. Radioactive substances need only be present in concentrations sufficiently high to affect reproduction, mobility, growth, etc. to cause harm to any organism. The total effect of accumulation in food chains is yet to be assessed.

Quantitative measures which summarize community structure clearly and briefly are useful in evaluating effects of wastewaters on aquatic life. The technical aspects of biology are such that data reduction is essential. One of the simplest and most promising methods of analysis is a diversity index. Diversity indexes are mathematical expressions which describe community structure and permit summarization of large amounts of information about numbers and kinds of organisms. Numerous measures of diversity have been advanced; one of the more promising diversity indexes, based on information theory, was proposed by Margalef (18). The component of diversity due to the distribution of individuals among the species, "equitability," has been evaluated by Lloyd and Ghelardi (19).

To protect fish and other aquatic life from harmful effects of wastewaters criteria for water quality management are necessary. Criteria in Georgia prescribed for the protection of fish, shellfish, and other aquatic life, and game (Environmental Protection Divison, Georgia Department of Natural Resources, 1) include a daily average of 5.0 mg/1 of dissolved oxygen with no less than 4.0 mg/1 at any time (trout waters with 6.0 mg/1 average and 5.0 mg/1 minimum), a fecal coliform bacterial limitation of 1000 per 100 ml sample, pH within a range of 6.0 to 8.5, and a maximum permissible temperature (in trout and smallmouth bass waters no change in temperature is permitted).

RESEARCH NEEDS

A myriad of research needs pertinent to wastewater discharge effects on fish, game, and wildlife exists. Important needs include the following:

1. Detailed population studies of fish and aquatic macroinvertebrate organisms to aid in estimating and assessing effects of various types of wastewaters are needed. Investigations should include determining general environmental requirements for balanced aquatic communities. Lethal and non-lethal limits for pollutants (including radiation) need to be established for the survival and normal reproduction of many species.

2. Improvements and standardization of taxonomy and methodology related to fish, game, and wildlife affected by wastewaters are needed. To be most meaningful accurate comparisons of various studies are essential; such comparisons of historical date cannot be made in many instances.

3. The ecological effects of wastewater discharges containing mercury, other heavy metals, and pesticides are in need of considerable additional study. Due to past uncontrolled discharges, the persistence and effects of mecuric compounds in aquatic environments is uncertain.

SUMMARY

Wastewater discharges are capable of pronounced effects upon all forms of life including aquatic and non-aquatic forms. Wastewater discharges resulting in water pollution are of chief public concern.

Fish and benthic macroinvertebrates serve as useful indicators of effects of wastewater discharges. Fish and benthic macroinvertebrate populations have been shown to be adversely affected by large wastewater discharges below major urban areas. Inorganic materials such as silt can completely decimate stream populations and render the habitat uninhabitable.

Excessive nutrients including nitrogen and phosphorus present in wastewaters may result in algal blooms, slime growths, or taste and odor problems in water supplies. Fish and other aquatic populations may increase due to increased productivity of enriched waters. Excessive algal blooms are also capable of causing oxygen depletion resulting in fish kills.

Toxic, and potentially lethal wastewater materials which may affect aquatic organisms include acids, mercury, pesticides, and detergents. Acids introduced into a Georgia stream seriously impaired water quality. Mercury in wastewater discharges is related chiefly to chlor-alkali industries. High levels of mercury have been found in Georgia in certain fish, crabs, and birds in areas of mercury discharges by a chlor-alkali plant.

Thermal effects may alter reproduction, growth, or ability of organisms to survive. Trout living below an extremely cold water discharge in Georgia were unable to reproduce. Turtles have been shown in our instance to grow larger and faster due to heated discharges.

Radioactive materials were mentioned briefly. Radiological effects are usually manifested in food chains through accumulation.

Effects of wastewaters regarding community structure may be expressed through use of diversity indexes and distribution of species.

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Chapter 12

WASTE WATER POLLUTION FROM THE MEAT PRODUCTS AND OFF-SITE RENDERING INDUSTRIES

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INTRODUCTION

The meat packing, meat processing and off-site rendering industries are certainly significant contributors to pollution in the Nation's stream. This pollution is also an economic loss to these industries, both from the standpoint of the cost of treating the waste waters and of the value of the material lost. While much has been done in recent years to reduce this waste and pollution load, in-plant modification and improvement in waste treatment systems can result in further pollution reduction.

The raw waste water load from a plant in these industries is the load prior to secondary treatment; it is dependent upon a number of factors, including plant size, processes and equipment used, and operating and housekeeping practices. Processes in the plant that reduce the waste water load include various kinds of grease traps, catch basins, and air flotation systems. These processes are often considered primary waste treatment in a plant, although they may have been installed originally to recover a by-product of value, rather than for pollution control.

Waste waters from the meat products and off-site rendering industries are high in organic matter (including grease) and contain various amounts of suspended solids, and inorganic materials such as phosphates, nitrogen compounds and salts. These materials enter the waste stream as blood, meat and fatty tissue, meat extracts, paunch (cattle rumen) contents, bedding, manure, hair, feathers, dirt, contaminated cooling waters, condensables from rendering, curing and pickling solutions, and alkaline detergents. There is no evidence of any purely hazardous or toxic pollutants (such as heavy metals or pesticides) in the wastes discharged from these industries.

Pollutant Parameters

The physical, chemical, and biological constituents of these waste waters that constitute pollutants as defined by the Federal Water Pollution Control Act Amendments of 1972 are:

BOD_5 (5-day 20°C biochemical oxygen demand)
COD (chemical oxygen demand)
Suspended solids (SS)
Total dissolved solids (TDS)
Total volatile solids (TVS)
Grease
Ammonia nitrogen (NH_3)
Total Kjeldahl nitrogen (TKN)
Nitrates and nitrites (NO_3 - NO_2)
Total phosphorus (TP)
Chloride (Cl)
Temperature
Bacteria
pH

Of the 14 pollutant parameters, BOD_5,SS, and grease are the ones most frequently reported. BOD_5 is an important measure of the oxygen consumed by microorganisms in the aerobic decomposition of the wastes at 20°C over a five-day period. More simply, it is an indirect measure of the biodegradability of the organic pollutants in the waste. BOD_5 can be related to the requirements for waste treatment or to the depletion of oxygen in a receiving stream. Depletion of dissolved oxygen (DO) in a stream will limit the varieties of fish that can survive; no fish can live below about 4 mg/l DO. Concentration of values of BOD_5 for the raw waste waters from three industries are:

	Raw Waste BOD_5 Concentration (mg/l)	
Industry	Maximum Range	Typical Range
Meat Packing	300-3800	900-1500
Meat Processing	70-2900	200-1200
Off-Site Rendering	100-9000	1000-5000

These values are high when compared with typical municipal waste water, which runs about 250 mg/l.

BOD_5 normally correlates well with SS, COD, and TVS.

Suspended solids measures the material that can be removed from the waste waters by laboratory filtration, but does not include coarse or floating matter that can be screened or settled out readily.

Total Kjeldahl nitrogen, which is a measure of the organic and ammonia nitrogen, is a good indicator of the crude protein in the effluent. Under anaerobic or septic conditions, organic nitrogen is converted to ammonia. Oxidation of ammonia and organic nitrogen in aerobic waste treatment systems results in the formation of nitrites and nitrates.

Raw Waste Characteristics

The raw waste characteristics of red meat and rendering plants can only be established, with confidence, if they are based on sufficient data. To do this requires that all waste load data be normalized--expressed as pounds of pollutant per 1000 pounds live weight killed, finished product produced, or raw material used--so that data from various plants can be compared.

Meat Packing Plants

It did not seem reasonable at the outset of our study to expect that all packing plants should have the same waste water characteristics; there are too many differences between plants. On the other hand, data were not adequate to take into account all differences. We concluded that the packing plants could be quite well categorized by differentiating first between slaughterhouses and packinghouses.

> A *slaughterhouse* is a plant that slaughters animals and has as its main product fresh meat, usually carcasses broken down no smaller than quarters.
>
> A *packinghouse* is a plant that both slaughters and processes fresh meat to cured, smoked, canned, and other prepared meat products.

Further subdivision of slaughterhouses permitted us to separate two classes: simple and complex. A simple slaughterhouse is one that does, at most, a very limited amount of processing of by-products; by-product processing includes paunch handling, blood processing, rendering, hide and hair processing, and viscera handling. A complex slaughterhouse does extensive processing of by-products.

Because packinghouses vary widely in the amount of further processing they do, they were subdivided into low-processing and high-processing packinghouses. A low-processing packinghouse processes no more than the total animals it kills. A high-processing packinghouse processes more than its own kill, bringing in carcasses from outside also.

The differences between the four subcategories and the relationships between them are shown schematically in Figure 1.

The primary waste water characteristic upon which the plants were grouped was BOD_5; and the units were lb/1000 lb live weight killed (LWK). Specific differences exist in the BOD_5 load for the four subcategories and these are presented in greater detail in reference 1.

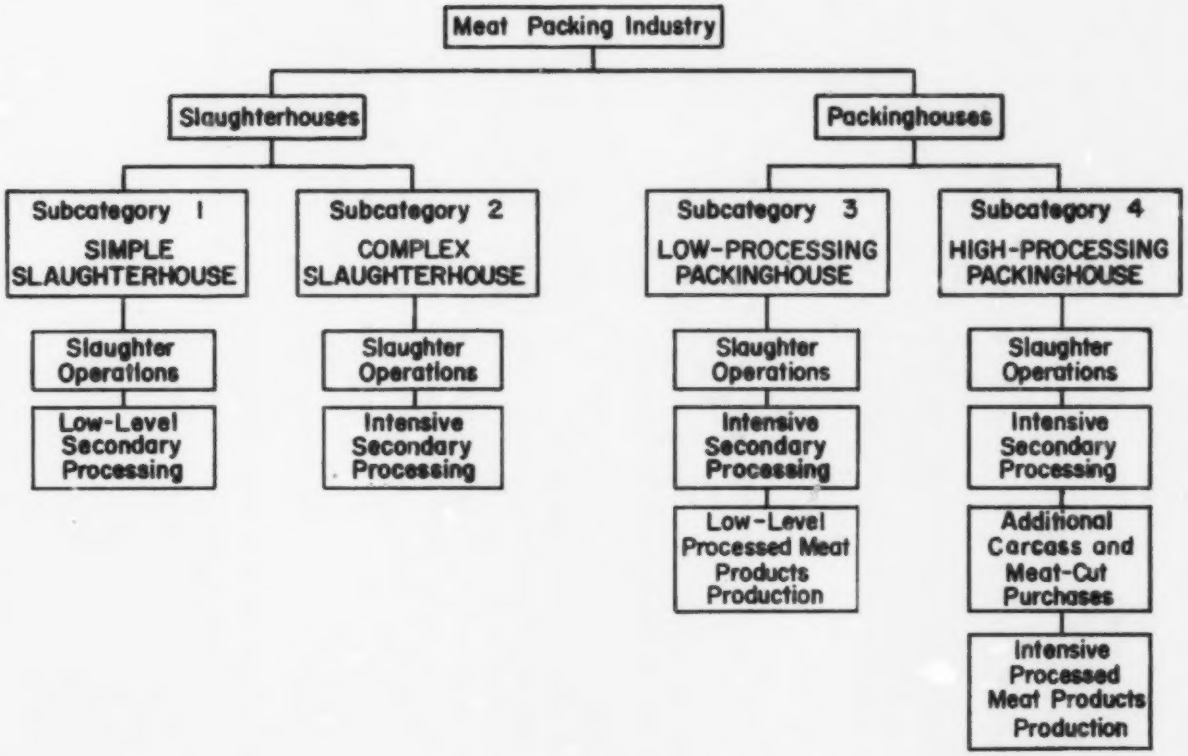
Meat Packing Industry
Slaughterhouses
Packinghouses
Subcategory 1 SIMPLE SLAUGHTERHOUSE
Subcategory 2 COMPLEX SLAUGHTERHOUSE
Subcategory 3 LOW-PROCESSING PACKINGHOUSE
Subcategory 4 HIGH-PROCESSING PACKINGHOUSE
Slaughter Operations
Low-Level Secondary Processing
Slaughter Operations
Intensive Secondary Processing
Slaughter Operations
Intensive Secondary Processing
Low-Level Processed Meat Products Production
Slaughter Operations
Intensive Secondary Processing
Additional Carcass and Meat-Cut Purchases
Intensive Processed Meat Products Production

Figure 1. Categorization of Meat Packing Plants

The BOD_5, suspended solids and grease characteristics of the raw waste for the various categories of meat packing plants are indicated in Figures 2 through 4; Figure 5 shows the raw waste water characteristics. The lowest, highest, and average values, plus the number of plants in each category are indicated for each bar graph in these figures.

Twenty-four of 85 plants analyzed were simple slaughterhouses. Of these 24, one-half were beef; the rest were divided between hogs and mixed kill. The average LWK was about 480,000 lb/day. The BOD_5 covers the range from 1.5 to 14.3 lb BOD_5/1000 lb LWK. Also, only small and medium plants were found in this category--two small and 22 medium (small plants kill less than 25 million lb/yr; medium, between 25 and 200 million lb/yr; and large, more than 200 million lb/yr).

Nineteen plants were complex slaughterhouses (11 beef, 6 hogs, and 2 mixed). About one-third of these plants were large and the rest, medium. The average kill was about 1,3000,000 lb LWK/day. BOD_5 ranged from 5.4 to 18.8 lb/1000 lb LWK, with an average of 10.9.

Twenty-three plants were low-processing packinghouses; all were medium or large. Nineteen were high-processing packinghouses, with two small, 11 medium, and 6 large plants. The low-processing plants had an average ratio of lb processed products: lb LWK of 0.14. The average size was 900,000 lb LWK/day. BOD_5 averaged 8.1 lb/1000 lb LWK, with a range of 2.3 to 18.4. The high processing plants had an average ratio of lb processed products to lb LWK of 0.65. However, the ratios varied widely, from 0.40 to 2.14; this wide range necessitated our taking the amount processed into account in assessing plant waste loads. The average kill was about 800,000 lb/day. The BOD_5 ranged from 6.2 to 30.5 lb/1000 lb LWK, with an average of 16.1 lb.

The average values and ranges for suspended solids and grease are shown in Figures 3 and 4, respectively. Somewhat fewer plants are represented, as indicated in the figures, because of the paucity of data.

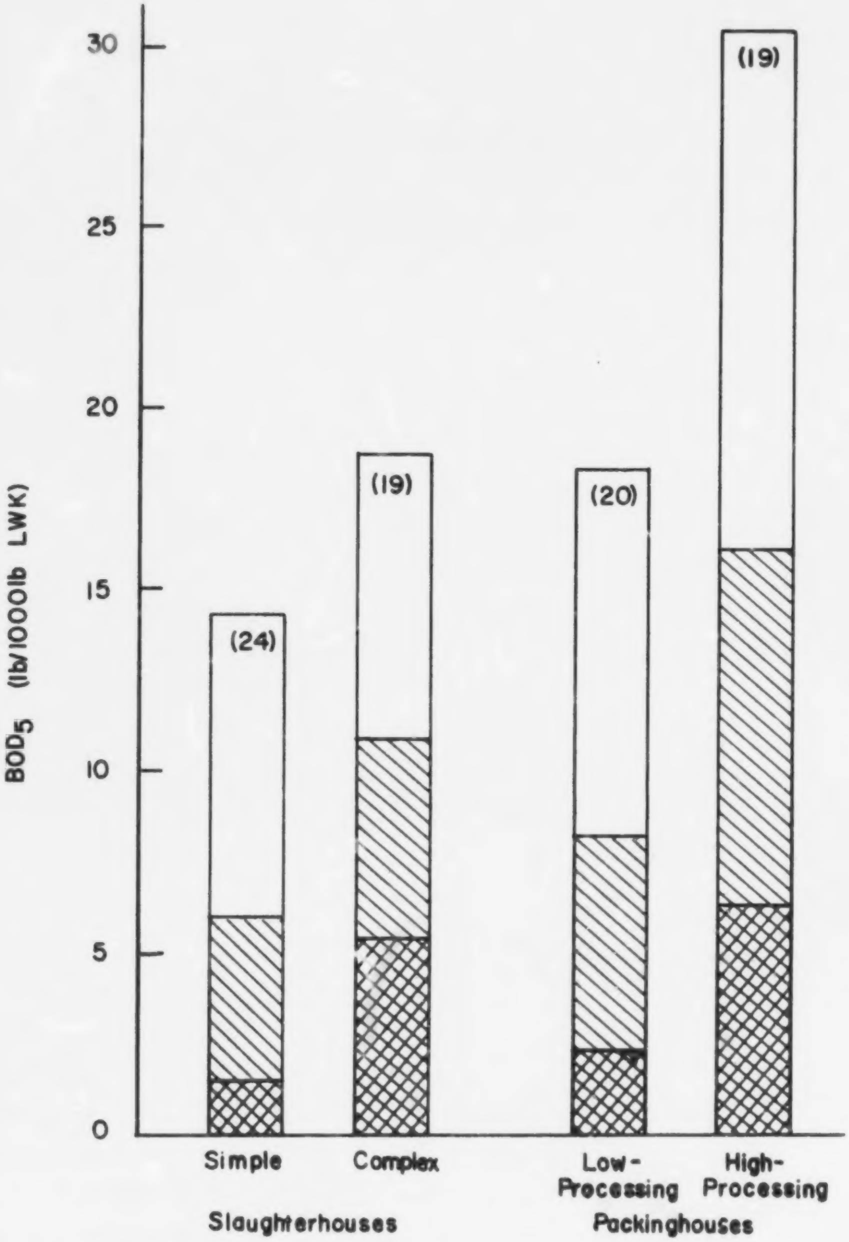

FIGURE 2. BOD_5 IN RAW WASTEWATER

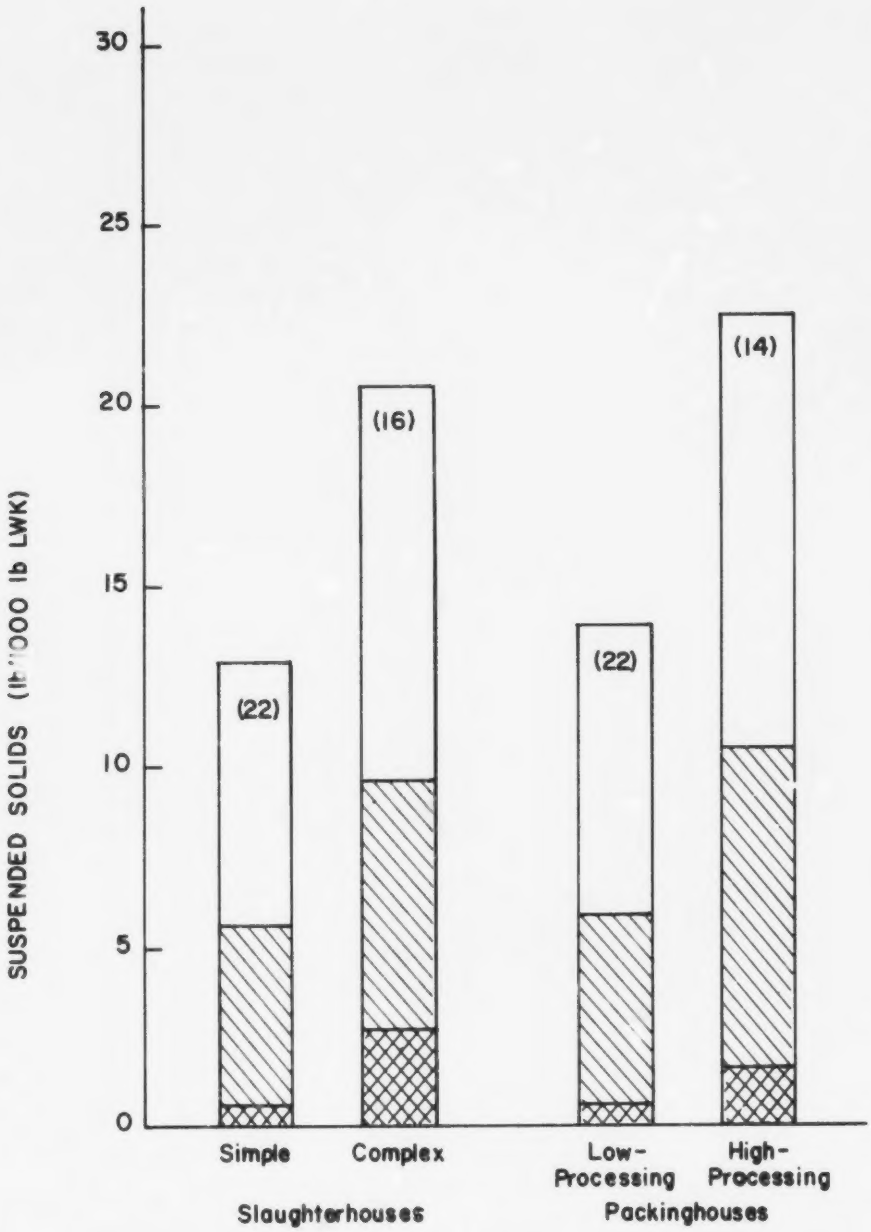

FIGURE 3. SUSPENDED SOLIDS IN RAW WASTEWATER

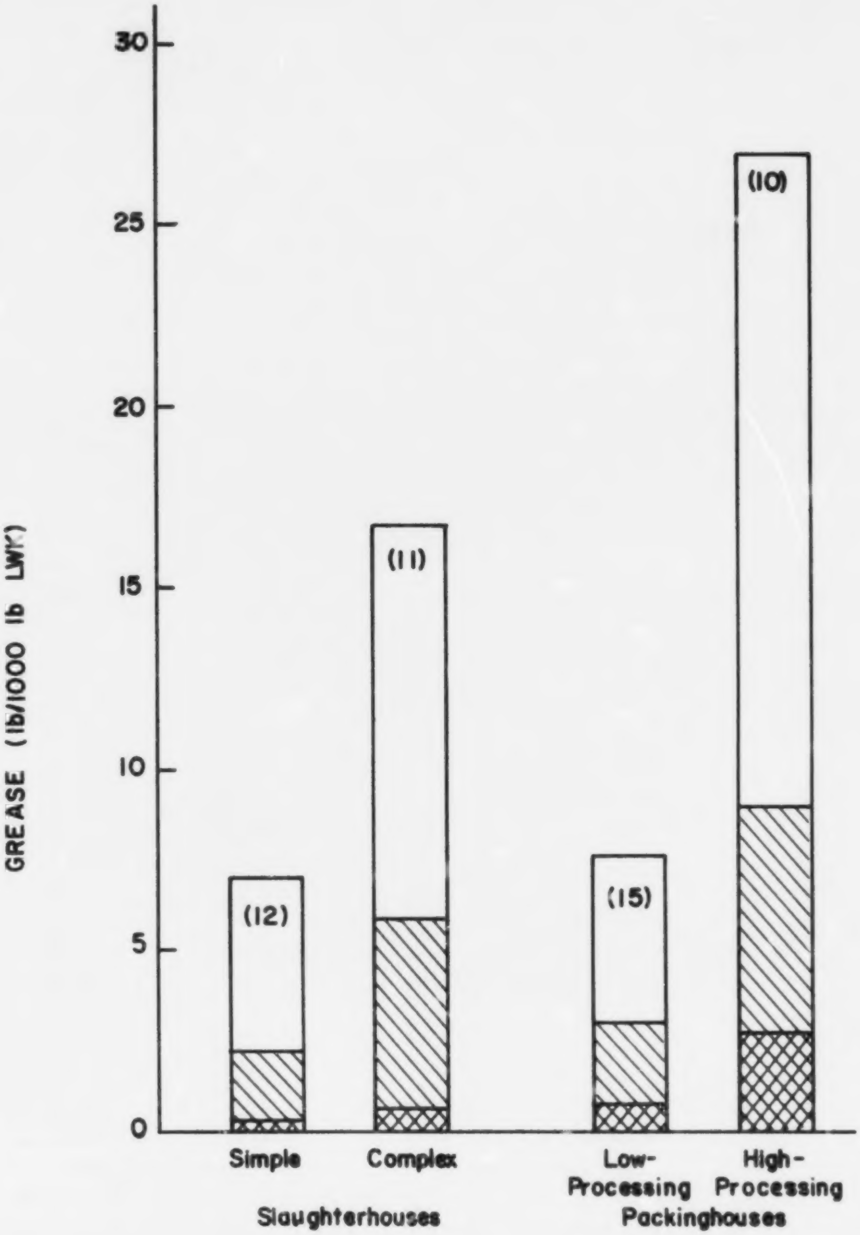

FIGURE 4. GREASE IN RAW WASTEWATER

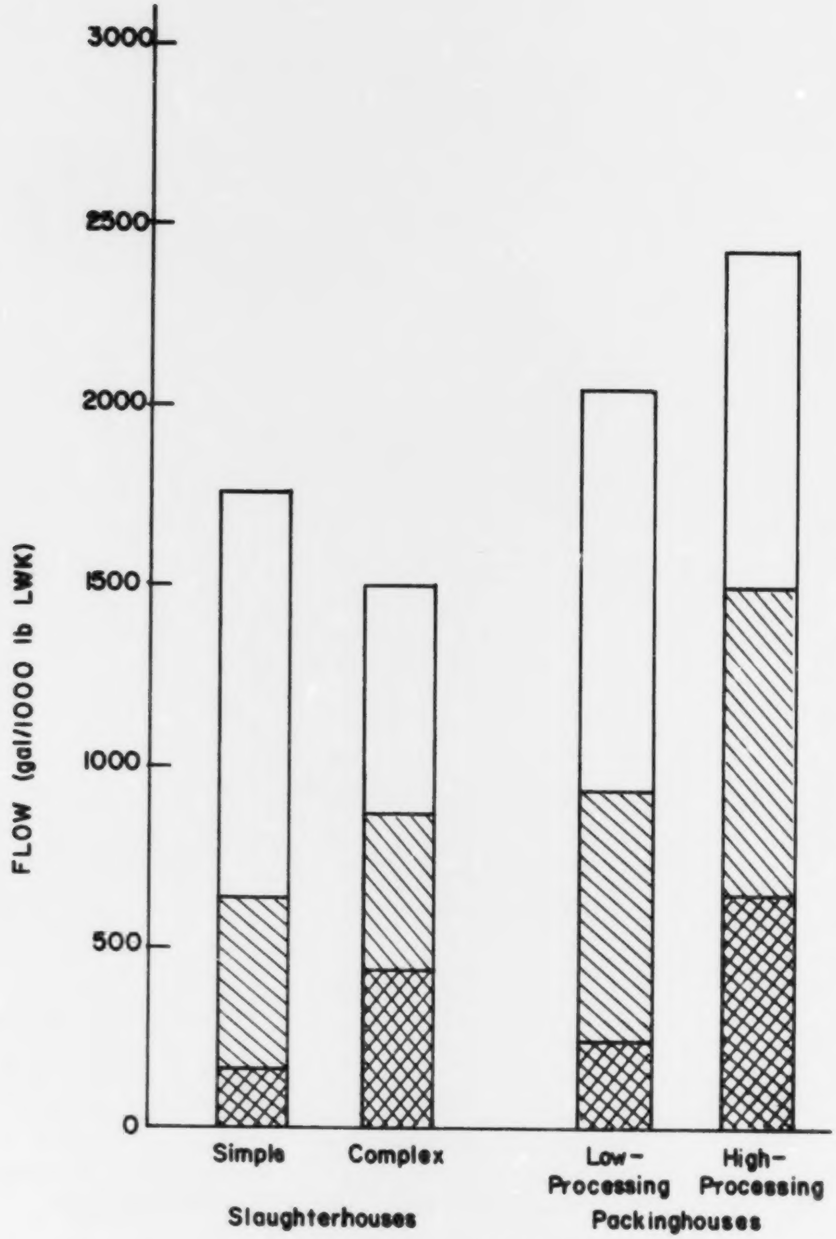

FIGURE 5. WASTEWATER FLOW

Figure 5 shows the waste water flows for the four plant subcategories. We can see a great range--from about fourfold to nearly elevenfold--within a given category. This is certainly a key to some of the waste load variation. In Table 1 are summarized some of the key average values from the preceding figures. The values here might define an average plant, or one that is typical of those surveyed. It can be noted that the waste water BOD$_5$ values vary roughly with the waste water flow.

The daily raw waste loads for average-sized meat plants will range from 2700 to 14,000 lb BOD$_5$ per day. At an average of about 0.20 lb BOD$_5$ per person per day for domestic waste, the 14,000 lb BOD$_5$ per day from a packing plant is equivalent to the domestic waste load from a city of about 70,000 people.

Table 1. Average Packing Plants

	Industry Subcategory			
	Simple Slaughter-house	Complex Slaughter-house	Low-Processing Packing-house	High-Processing Packing-house
Kill (lb LWK/day)	484,000	1,310,000	900,000	800,000
Wastewater flow (gals/1000 lb LWK)	639	885	941	1,500
Raw waste, BOD$_5$ (lb/1000 lb LWK)	6.0	10.9	8.1	16.1
Processed meat production (lb/day)	0	0	119,000	422,000

Relatively little information is available for meat packing plants on waste parameters such as Kjeldahl nitrogen, ammonia, nitrites, nitrates, and total dissolved solids. Information from the literature and from our field studies suggested that concentrations generally fell in the following ranges:

Ammonia as N, mg/l	7 - 50
Kjeldahl nitrogen, mg/l	50 - 300
Nitrates and nitrites as N, mg/l	0.01 - 0.85
Total phosphorus as P, mg/l	6 - 36
Total dissolved solids, mg/l	500 - 25,000

Meat Processing Plants

Meat processing plants conduct the same *processing* operations carried out in meat packinghouses, but they do not engage in slaughtering. The combinations and sizes of processing operations; however, vary greatly among processing plants, as do the waste water flows and loads.

Typical raw waste load ranges for processing plants, in units of pounds per 1000 pounds of finished product, are 0.5 to 11.0 for BOD_5, 0.6 to 4.5 for suspended solids, and 0.1 to 2.0 for grease; the typical waste water flow range is 70 to 1350 gallons per 1000 pounds finished products. The lower end of the ranges is characteristic of the waste loads from plants that only do meat cutting, while the upper values are characteristic of loads from plants that produce canned products. Plants that produce sausage and luncheon meats and plants that produce hams will normally have waste load values that are intermediate in the above ranges.

Off-Site Rendering Plants

Figures 6 and 7 are bar graphs indicating the average, and low and high values of 12 pollutant parameters for the raw waste waters from off-site rendering plants. The number of plants included in the data analysis for each parameter is shown in parenthesis in the bar graphs. All data are presented in units of pounds of pollutant per 1000 pounds of raw material (RM).

The data show that there is a wide range of values for most parameters; much of this variation is probably caused by variations in housekeeping practices, drainage of high strength liquids from raw materials into sewers, overflow and leakage from processing equipment, and ineffectiveness of in-plant primary treatment. The waste water flow rates and production for rendering plants also covered a broad range, although these factors did not affect the waste loads to any noticeable degree. The waste water flow range for all plants studied varied from 56 to 9700 gallons per 1000 pounds RM; the production varied from 8000 to 860,000 pounds RM per day. An average size plant would have a production rate of 206,000 pounds RM per day and a waste water flow of 597,000 gallons per day.

Variations in waste water flow per unit RM are largely attributable to the types of condensers used for condensing cooking vapors and, to a lesser extent, on the moisture content of the raw materials.

Sources of Wastes

Meat Plants

The sources of wastes in meat plants are the slaughtering, meat processing, by-product and clean-up operations. The major sources of pollutants from slaughtering come from blood handling, carcass washing, hog scalding and dehairing, stomach and peck flushing, paunch handling, and chitterling and casing washing. The largest potential source, however, is blood. Typically, 35 pounds of blood are recovered per head of cattle, with up to 15 pounds lost

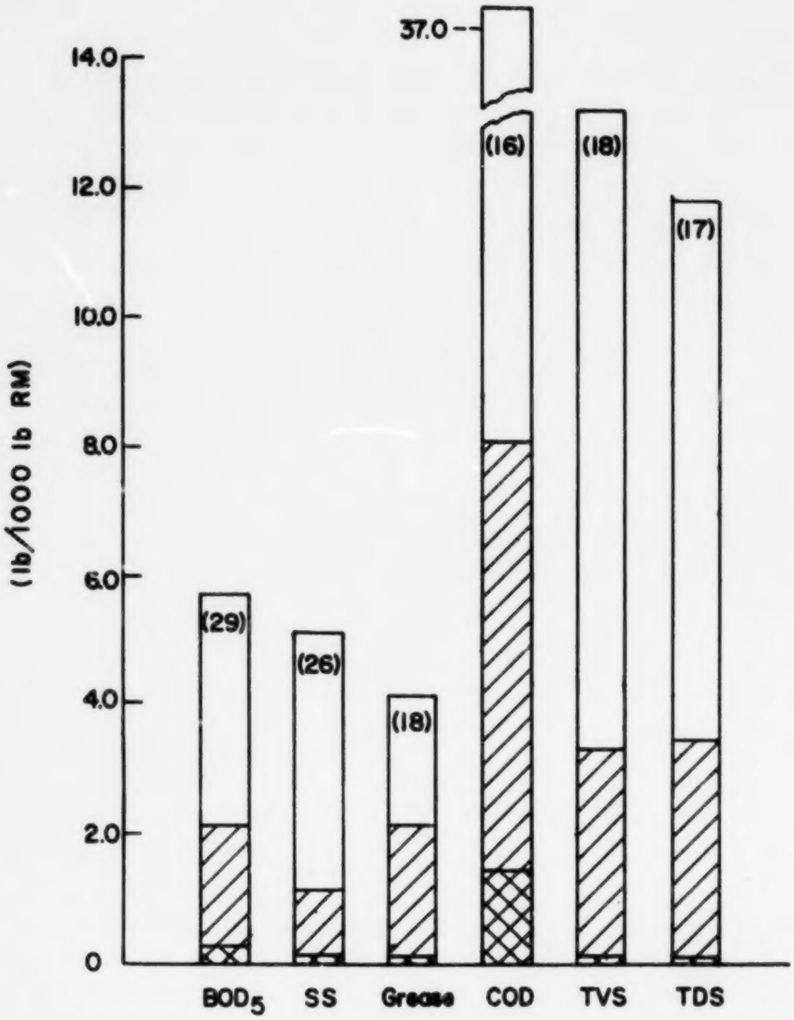

FIGURE 6.

RAW WASTE WATER DATA FOR OFF-SITE RENDERING PLANTS

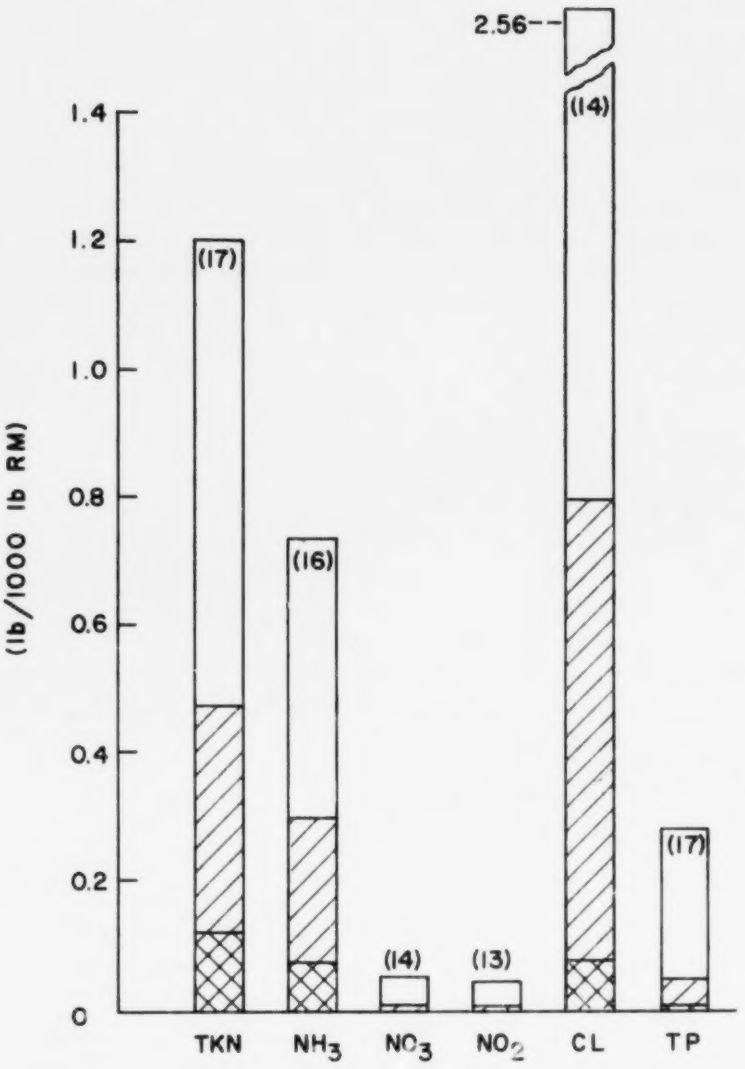

FIGURE 7.

RAW WASTE WATER DATA FOR OFF-SITE RENDERING PLANTS to the sewer. This loss would produce a waste load of 2.25 to 3 pounds BOD_5/1000 pounds live weight killed. Wet dumping of paunch can also add a significant load--probably 1.5 pounds BOD_5/1000 pounds LWK--because 60 to 80 percent of the BOD_5 in paunch is water souble.

The major source of pollutants from meat processing is from curing and pickling operations. In some cases, only about 25 percent of the curing brine remains in the product.[2] The dextrose used in cure has a BOD_5 equivalent of 2/3 pound BOD_5/pound dextrose. Other sources of pollutants from processing are meat and fat particles, and meat extract resulting from sawing, cutting, and grinding operations. These pollutants normally enter the sewer during clean-up operations.

Off-Site Rendering Plants

Major sources of pollutants from off-site rendering plants are liquid drainage from raw materials in the receiving areas, vapor condensing, and spills and plant and truck clean-up. Other sources are odor control, hide curing, and the sewering of tankwater and blood water. Fortunately, dry rendering, which does not produce any tankwater or blood water, is used almost exclusively by off-site renderers. Tankwater and blood water can have BOD_5 and grease concentrations as high as 30,000 to 45,000 mg/l and 20,000 to 60,000 mg/l, respectively.

Effluent Characteristics

Meat Packing Plants

The final effluent characteristics, following biological treatment, are shown in the following figures. Figure 8 shows the data for BOD_5, suspended solids, grease, total Kjeldahl nitrogen (TKN), and ammonia nitrogen for simple slaughterhouses. The range for values for the six plants is shown, along with an average. Data were available for fewer plants for grease, TKN, and

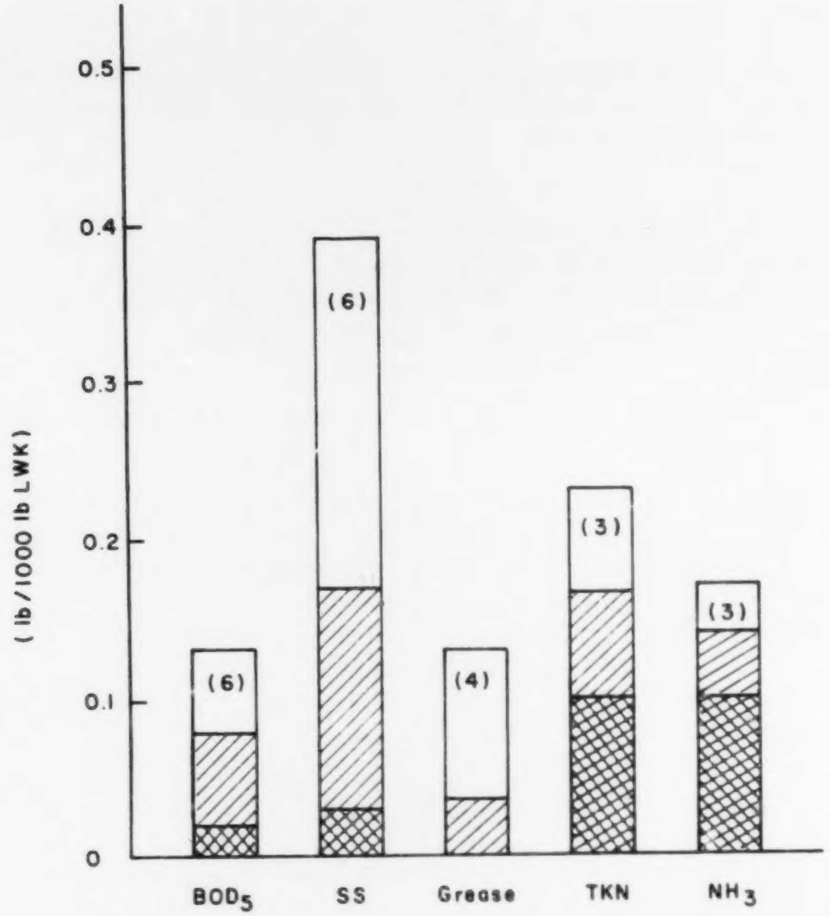

FIGURE 8. EFFLUENT DATA FOR SIMPLE SLAUGHTERHOUSES

ammonia, as noted in the figures. Suspended solids tend to be the most widely varying, and is one of the most difficult pollutants to control. It depends, of course, on the algae growth and the operation of the final aerobic or polishing lagoon.

Figure 9 shows data for complex slaughterhouses. This category includes most of the newer, very large slaughterhouses. The data scatter considerably. The variability generally reflects the variability in raw waste load for these plants.

Figure 10 shows the values for the low-processing packinghouses. The same information is shown for high-processing packinghouses in Figure 11. The much greater variability in the data shown in this figure reflects the wide range of raw waste loads, which in turn results at least in part from the range in the amount of processed products.

Meat Processing Plants

Our survey of meat processing plants indicates that 80 to 90 percent of the plants discharge their waste to municipal treatment systems. Consequently there was insufficient data to characterize treated waste from meat processing plants. However, the similarity in raw waste characteristics between meat packing and meat processing plants would indicate that meat processing waste water could be reduced to the same final effluent concentrations as meat packing wastes using similar biological treatment. The limited final effluent data also indicate this to be the case.

Off-Site Renderers

Final effluent values for BOD_5, suspended solids, grease, total Kjeldahl nitrogen as N, and ammonia as N, following biological treatment, are shown in Figure 12 for off-site rendering plants. The range and average values are shown as is the number of plants represented by the data. Values for all the

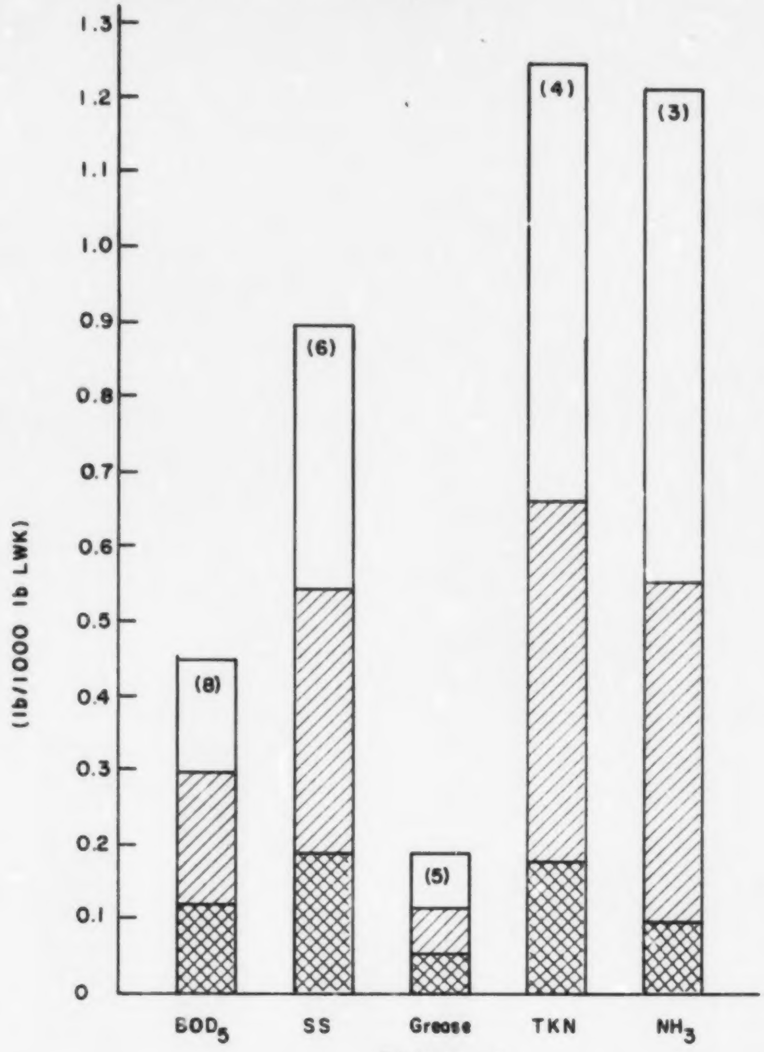

FIGURE 9.

SELECTED EFFLUENT DATA FOR COMPLEX SLAUGHTERHOUSES

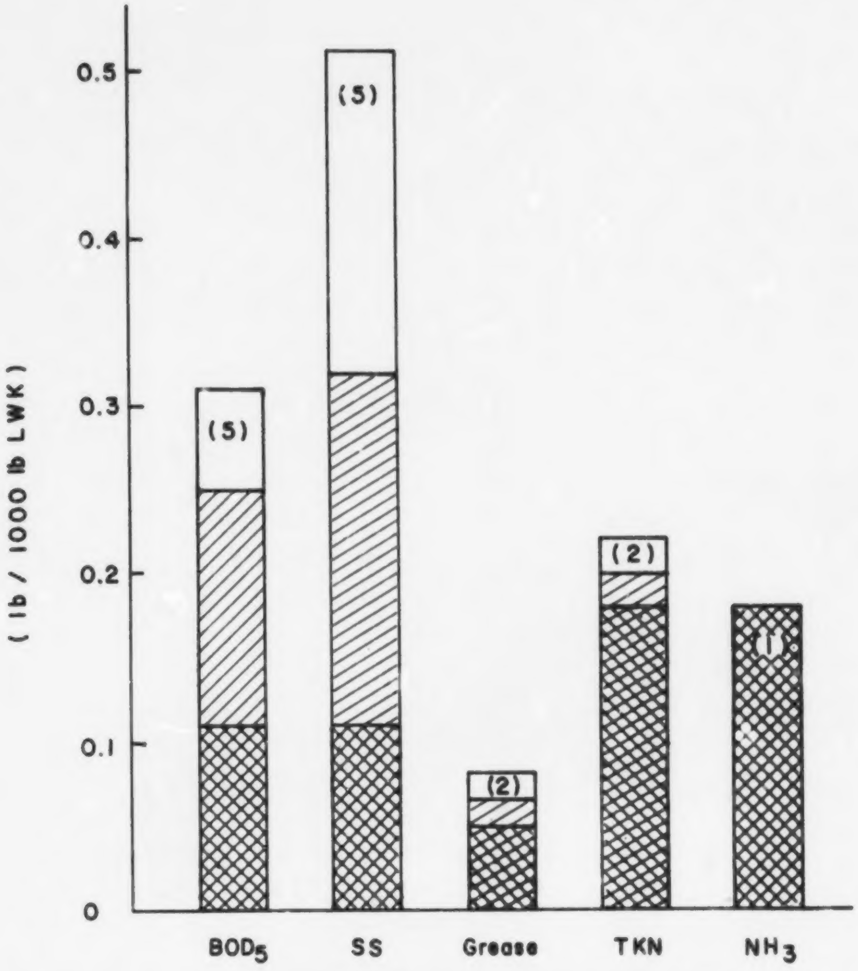

FIGURE 10. SELECTED EFFLUENT DATA FOR LOW-PROCESSING PACKINGHOUSES

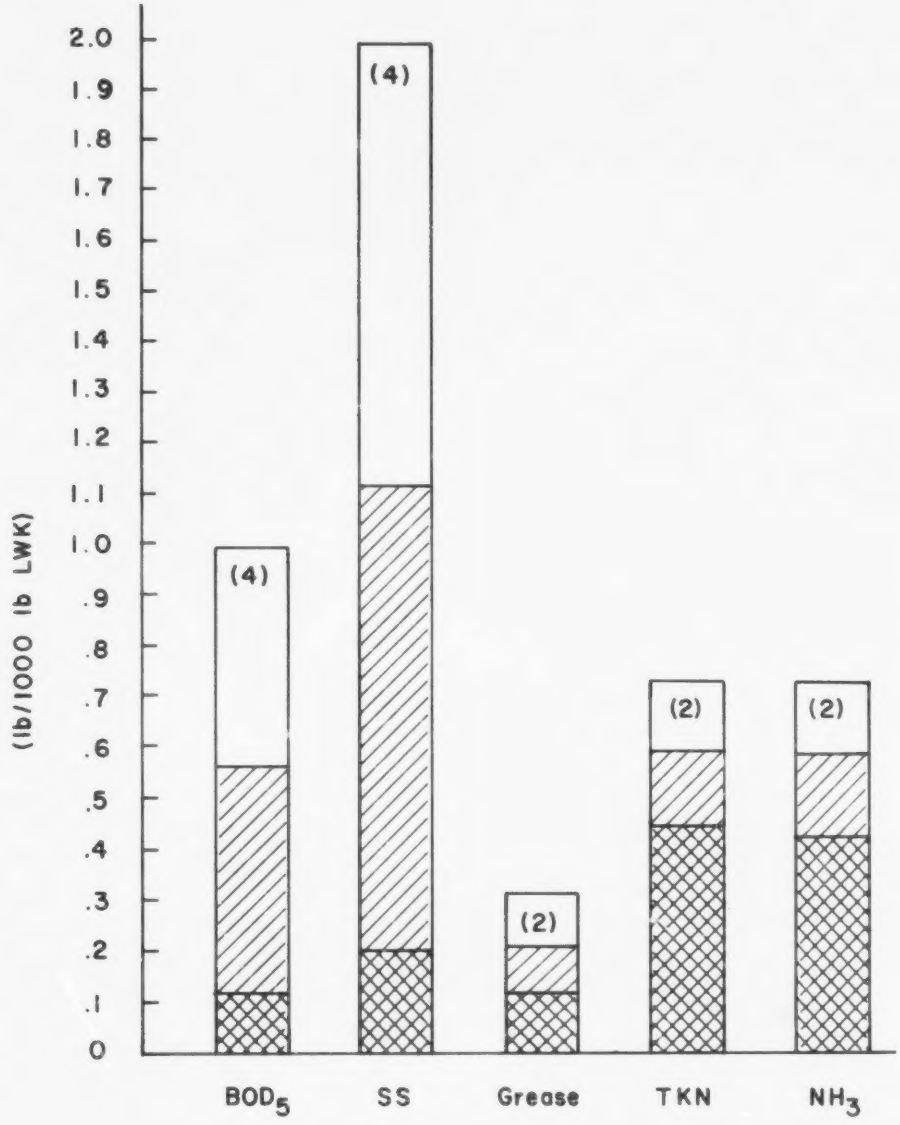

FIGURE 11.
SELECTED EFFLUENT DATA FOR
HIGH-PROCESSING PACKINGHOUSES

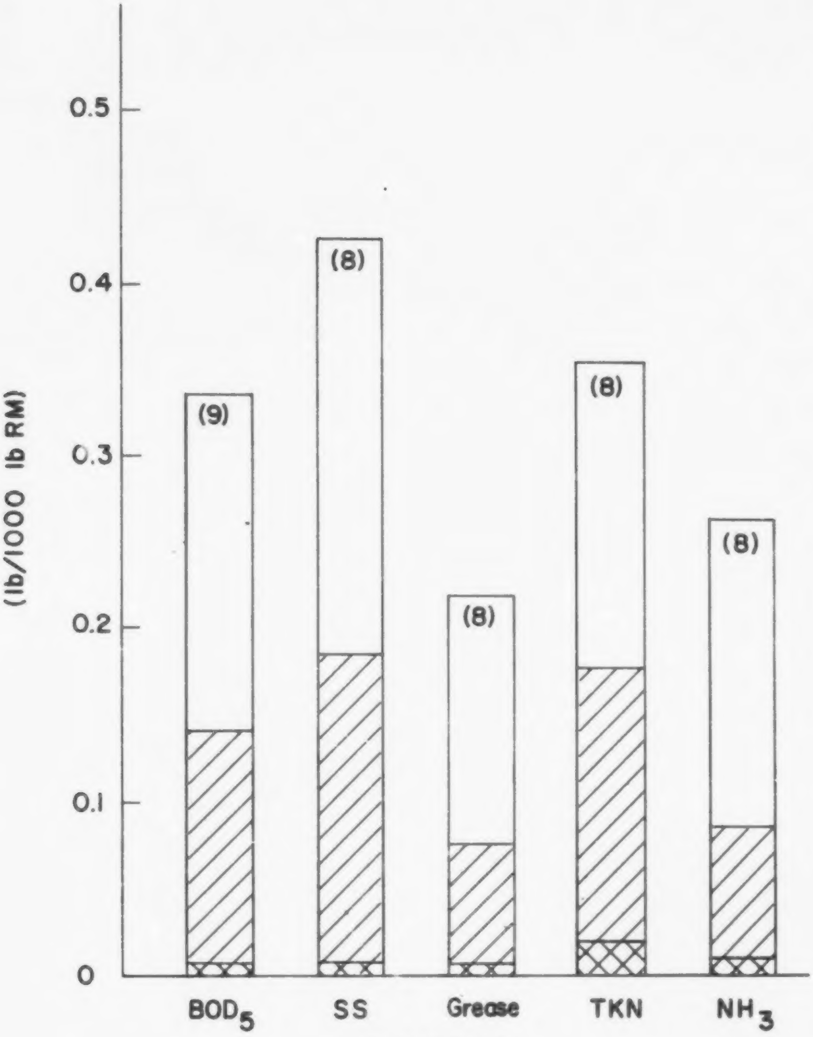

FIGURE 12.

SELECTED EFFLUENT DATA FOR OFF-SITE RENDERING PLANTS parameters shown tend to vary considerably. This is probably because of variation in the degree of biological treatment and a reflection of raw waste variations. In addition, data analysis and analytical tests indicate that suspended solids control or limit BOD_5 in the final effluent. Hence, filtering suspended solids out of the biologically treated wastes would lower the final effluent load even more than indicated in Figure 12.

Nitrate and nitrite loads (not shown in Figure 12) for eight plants average about 1×10^{-3} pound N/1000 lb RM. A comparison of the data for raw waste and final effluent reveals a loss of nitrogen across the biological treatment system. It is possible that this is a result of the two-step process of nitrification-denitrification occurring within the large resident-time biological treatment systems being used by the industry.

Total phosphorus values averaged 0.03 lb/1000 lb RM, or about the same as in the raw waste.

Discharges

Table 2 presents calculated daily discharges of pollutants in the final effluents for average-sized meat packing and off-site rendering plants. These values were calculated using average production rates for each category and the corresponding effluent characteristics presented in the previous section.

The values of Table 2 indicate that average-sized complex slaughterhouses and low- and high-processing packinghouses discharge considerably more pollutants than an average-sized simple slaughterhouse or off-site rendering plant.

Table 2. Calculated Daily Pollutant Discharges for Average-Sized Plants

Parameter	Pounds Per Day				
	Slaughterhouses		Packinghouses		Off-Site Rendering
	Simple	Complex	Low Processing	High Processing	
BOD_5	39	393	223	438	29
SS	86	716	282	877	39
Grease	17	148	56	164	16
TKN	83	865	178	478	36
NH_3	70	730	158	466	17

Primary Treatment

Primary treatment, which in these industries is an in-plant process, varies widely in performance. Much of this variation is caused by operating these systems at rates significantly different from their design capacity, lack of attention, and poor flow equalization.

Primary treatment systems include grease traps, catch basins, screens, air flotation tanks, and flow equalization tanks.

The ranges of effectiveness for gravity systems are:

	Grease	Suspended Solids	BOD_5
Air flotation	70 - 90	50 - 65	20 - 35
Catch basin	30 - 60	40 - 50	10 - 20

Some improvement is obtained by combining catch basins and flotation. Air flotation can be made even more effective by the addition of a polymeric flocculating agent. pH control at near the isoelectric point of the protein in the waste appears to increase the effectiveness still further.

Performance of Various Biological Treatment Systems

Table 3 shows BOD_5, suspended solids (SS), and grease removal efficiencies for various biological treatment systems on rendering plant and meat packing plant waste waters. Best values each represent results from an actual treatment system, except for the data on the anaerobic plus aerobic lagoon system under treatment on meat packing waste waters, which includes two plants. The number of systems used to calculate average values is also shown in Table 3. It is apparent that the anaerobic plus aerobic lagoon system is the one most commonly used by meat packing and rendering plants.

Table 3. Performance of Various Secondary Treatment Systems

	Secondary Treatment System (number of systems used to determine averages)	Water Wasteload Reduction (percent)					
		Average Values			Best Values		
		BOD_5	SS	Grease	BOD_5	SS	Grease
Rendering Plants	Anaerobic + Aerobic Lagoon (4)	97.7	97.3	89.2	99.0	99.9	99.4
	Activated Sludge (2)	93.7	86.1	92.2	96.6	97.1	99.4
	Aerated + Aerobic Lagoon (2)	96.9	88.2	77.5	97.7	93.8	78.8
Meat Packing Plants	Anaerobic + Aerobic Lagoon (22)	95.4	93.5	95.3	98.9	96.6	98.9
	Anaerobic + Aerated + Aerobic Lagoon (3)	98.3	93.3	98.5	99.5	97.5	99.2
	Anaerobic Contact Process + Aerobic Lagoon (1)	98.5	96.0	99.0	98.5	96.0	99.0
	Extended Aeration + Aerobic Lagoon (1)	96.0	86.0	98.0	96.0	86.0	98.0
	Anaerobic Lagoon + Rotating Biological Contactor (1)	98.5e	--	--			
	Anaerobic Lagoon + Extended Aeration + Aerobic Lagoon (1)	98e	93e	98e			
	Anaerobic Lagoon + Trickling Filter (1)	97.5	94.0	96.0	97.5	94.0	96.0
	2-Stage Trickling Filter (1)	95.5	95.0	98.0	95.5	95.0	98.0
	Aerated + Aerobic Lagoon (1)	99.4	94.5	--	99.4	94.5	--
	Anaerobic Contact (1)	96.9	97.1	95.8	96.9	97.1	95.8

e = estimated

The estimated reduction of BOD_5 for meat packing wastewaters shown for the anaerobic lagoon plus rotating biological contactor is based on preliminary pilot-plant results.[3] The values shown for the anaerobic lagoon plus extended aeration system are based on estimates of their combined effectiveness.

The data of Table 3 show that, for rendering plants, the anaerobic plus aerobic lagoons are the most effective system of those studied for BOD_5, SS, and grease removal. Furthermore, the anaerobic plus aerobic lagoon system appears, by percent reductions, to be more effective on rendering than on meat packing waste waters. This conclusion could be the result of an insufficient number of observations; however, it most likely is because the rendering waste loadings in the treatment system were frequently low. In fact, the BOD_5 waste loadings to this type of system for three of the rendering plants were 0.8, 7.8, and 2.2 lb BOD_5/1000 cubic feet, respectively. The usual design loadings are in the range of 15 to 20 lb BOD_5/1000 cubic feet.

In general, anaerobic plus aerobic lagoons that are properly sized perform well for BOD_5 and grease. A mechanically aerated stage between the two lagoons increases the effectiveness. Suspended solids can be reduced to very low levels if algae are not a serious problem. Various types of activated sludge systems can be very good, but tend to give high suspended solids. To achieve the low levels that may be required, combinations of systems probably will be needed. For example, anaerobic lagoons and digesters greatly reduce the organic content, but permit development of high ammonia levels. Aerated systems, such as extended aeration and rotating biological contactors, can be effective in nitrification, converting the ammonia to nitrites and nitrates. Large aerobic lagoons tend to become anaerobic near the bottom, and appear to accomplish denitrification. However, a great deal of further work in this area is certainly needed. Trickling filters are effective as a first stage or preliminary treatment. Completely aerobic systems, which avoid the obnoxious problems of anaerobic systems, may offer the best balanced treatment. However, mechanical aeration will be required at an increase in power cost.

Present biological treatment systems do little for either phosphorus or total dissolved solids. Phosphate is assimilated by algae; it, in effect, is converted to suspended solids. It can, however, be reduced to low levels in pretreatment stages. Salt and other dissolved solids usually go through the system unaffected. Their entry into waste water needs to be prevented whenever possible; removal by ion exchange or membrane processes would be costly. Ultimately, reduction of ammonia and dissolved solids may require tertiary treatment.

Irrigation may be the best technique in the near future, returning the nutrients to the soil for production of useful crops. This may follow only primary treatment, or biological treatment stages may also be involved before irrigating. In some industries, pipelines up to several miles in length are economically feasible for conveying waste water to irrigation sites.

CONCLUSIONS

The most important improvements to reduce waste loads in meat and rendering plants involve reduction of water use and strong implementation of good housekeeping practices. These, plus a good biological treatment system, can generally reduce losses and effluent values to those obtained by the best in the industry today. Current technology in many cases finds dissolved solids and nitrogen the most difficult to deal with. It seems unlikely that ammonia stripping with discharge to the atmosphere is a long-range solution to ammonia removal. The current state of development of nitrification-denitrification systems does not always assure a solution to the nitrogen problem. It appears that the industry has its work cut out for it in the next few years to approach the zero discharge that the Congress has as its ultimate goal.

Acknowledgment

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Chapter 13

AGRICULTURAL CHEMICALS AND WATER QUALITY

H. Page Nicholson

ABSTRACT

Man's agricultural activities contribute pesticides and plant nutrients to surface and ground water causing a variety of adverse environmental effects. Runoff, aerial transport, and carelessness (including accidents) all contribute to water pollution.

Prevention of pollution by agricultural chemicals, classified as non-point source pollution, must be accomplished by astute management rather than by the use of waste water treatment systems. Research is being done to develop simulative mathematical models for predicting the environmental impact of various agricultural management systems, to develop alternative methods of pest control, and to develop improved agricultural chemicals formulations in terms of their contribution to water pollution.

AGRICULTURAL CHEMICALS AND WATER QUALITY

H. Page Nicholson

INTRODUCTION

The public repeatedly expresses its concern regarding the adverse effects of agricultural chemicals upon the environment. Among the more evident effects in the aquatic environment are sudden fish kills caused by pesticides and the decline of lake values caused by eutrophication. Also of significance are subtle or indirect effects that sometimes may be extremely difficult to detect and define. For example, it took nearly 25 years to recognize and explain a number of the adverse environmental effects associated with DDT usage, such as the egg-shell thinness syndrome caused by a degradation product, DDE.

Water quality impairment by agricultural chemicals has been associated with rainfall runoff from agricultural and forest lands, deliberate application to water to control unwanted pests, accidental spills, careless or illegal use or disposal, airborne dusts and vapors, industrial manufacture or use, and municipal storm and wastewater discharges. This discussion is limited to water pollution associated with the use of these chemicals in agriculture.

Pesticides

About 665 basic pesticidal compounds are listed in the authoritative four-volume series by W. T. Thompson entitled Agricultural Chemicals (12). These include 174 insecticides; 140 herbicides; 137 fumigants, growth regulators, repellents, and rodenticides; and 114 fungicides. I estimate that no more than one-third are commonly used and that probably 50 make up 90 percent of all pesticides sold today. The basic or technical grade compounds themselves are not generally used in agriculture. They are formulated and packaged as dusts, wettable powders, solutions, emulsifiable concentrates, baits, or gases depending upon their individual characteristics and intended uses. The formulation and the method of its application determine, in part, whether or not a pesticide will constitute an environmental hazard. Approximately 35,000 formulations have been registered in the United States. In 1971, U. S. production of basic pesticides was estimated at 516 million kilograms (1,136 million pounds) and agricultural land treated for pest control was about 58 million hectares (143 million acres) (4).

Although many factors determine the effects of pesticides on aquatic communities, several characteristics of the pesticides are of primary importance. Among these are toxicity, persistence, and the tendency to bio-accumulate because of lipid solubility. The chlorinated hydrocarbon insecticides exemplified by DDT are particularly troublesome.

In the aquatic environment, pesticides may enter organisms either directly through absorption or indirectly through contaminated food. Cell division, photosynthesis, and growth may be affected; metabolic pathways may be changed; and enzyme systems may be inhibited. The vitality of developing immature life forms may be affected, leading to reduction in populations. Acute poisoning may result in immediate kills. If the degree of exposure to a pesticide exceeds the capacity of the organism to detoxify and eliminate it, a structural imbalance in an entire aquatic community may occur (10).

Factors that tend to mitigate the adverse effects of pesticides in the aquatic environment are dilution, chemical and microbial degradation, and absorption on sedimentary materials followed by deposition. Deposition, however, is not always an effective removal mechanism since the pesticide may accumulate in the bodies of bottom burrowing organisms or be released into the water if sedimentary materials are disturbed.

Runoff

Runoff is probably the single most common cause of low level fresh water contamination by pesticides (8). Pollution by pesticides through runoff may be more or less continuous throughout the year at levels generally less than 1 ug/1 (9) or may occur sporadically and seasonally (6). Transport from land to water may occur while the pesticide is absorbed on eroded soil or detritus, while in solution in water, or as Wershaw _et al_. (13) have shown, while dissolved in common organic soil constituents such as sodium humate.

Among the factors that determine the runoff potential of a pesticide are its persistence, extent of usage, rate of application, nature of the formulation, edaphic considerations, climate, topography, land usage, and land management practices. Pesticides having short half-lives do not possess the runoff potential of persistent types such as the chlorinated hydrocarbons. High humus soils will release less pesticide than will sandy soils. Heavy rainfall shortly following application of an insecticide is a classic cause of runoff that sometimes causes fish kills. A spectacular example occurred in August of 1950 across northern Alabama when intense thunder showers washed cotton poisons into 14 tributaries of the Tennessee River (15).

Aerial Transport

Transport through the air with subsequent direct deposition or runoff into water is an important means of distribution that is probably responsible for the world-wide dissemination of DDT. Pesticides become airborne by several methods. Drift of dusts and sprays during the pesticide application process, particularly aerial application, frequently contaminates adjacent land and water. Some pesticides volatilize from the soil and from treated vegetation to be transported as vapors. Finally, wind eroded soil bearing absorbed pesticides may be transported great distances. Dust deposited on Cincinnati, Ohio, in January 1965, originating from the plains of Texas and adjacent states, was shown to contain 0.6 mg/kg DDT, 0.5 mg/kg chlordane, 0.2 mg/kg DDE, 0.2 mg/kg Ronnel, 0.04 mg/kg heptachlor epoxide, 0.04 mg/kg 2,4,5-T, and 0.003 mg/kg dieldrin (3). Woodwell *et al.* (14) have developed a global model describing the circulation of DDT residues is from the land through the atmosphere, with the oceans being the greatest recipient since they cover most of the earth's surface.

Carelessness and Accidents

Carelessness and accidents resulting in water pollution associated with agricultural use of pesticides is not as prevalent today as it once was. This improvement may be credited to users' experience and intensive educational efforts on the part of manufacturers and public agencies. In the late 1940's and early 1950's when the synthetic organic pesticides first became generally available, one frequently heard of fish kills following the clean-up of a spray rig in a creek or the dumping of the remains of a tank of pesticide too near a pond.

A type of accident more difficult to control and still encountered is associated with pesticide application by air. This situation is compounded by high crop prices and a tendency to farm to the creek or lake edges. It is extremely difficult for a pilot to shut off his dispenser at the precise moment that will assure good pest control at the ends of the crop rows, yet avoid deposition of pesticide on closely adjacent water.

Consequences of carelessness can be tragic. An incident in Florida, 1964 (7) illustrates this point, though its destructive results were fortunately averted. A ranch employee, who had been instructed to dispose of approximately fifty 1.8 kg (4-pound) bags of 15 percent parathion dust, threw them into the Peace River approximately one mile upstream from the municipal water intake of Arcadia, a town of about 6,000 people. Later, some boys fishing near the site hooked a bag and had the foresight to report it.

The town fortunately had an auxiliary well and immediately reverted to it. The citizens were instructed not to use the water from the taps, and flushing of the mains was begun. Chemical analysis showed that the parathion concentration in the distribution system after flushing was generally less than 1 ug/1. However, a series of samples taken from a tap at the local bus station contained parathion in amounts up to 380 ug/1.

Investigation revealed that the bags of parathion had been dumped into the river about 10 days before their discovery. The bags were polyethylene lined and resisted rapid disintegration. Many were recovered unbroken and those that disintegrated apparently did so intermittently over a period of several weeks. This may be why the parathion did not reach levels high enough to be dangerous to the health of humans or fish. All but 8 to 12 bags were eventually found. Parathion residue occurred in river water for about two weeks after discovery at levels generally less than 1 ug/1.

Plant Nutrients

Man's activities would tend to upset any state of equilibrium that may have existed between the nutrient input to many lakes, streams, and estuaries and the ability of resident organisms to utilize those nutrients. Excessive nutrient input thus represents water pollution, often resulting in undesirable aquatic plant growths that limit various water uses and in oxygen depletion associated with plant decomposition. It also accelerates aging of water bodies, developing of lower value resident aquatic animal populations, and decline of shoreline values. In some localities nitrogen contamination of ground water approaches or exceeds the upper limit of suitability for human and animal consumption (10 mg/1 of nitrate-N).

The plant nutrients usually considered in any discussion of water pollution are nitrogen and phosphorus, which come from many sources. Goldberg (5) presented estimates of the contributions of these nutrients to water from various sources in terms of millions of pounds per year as follows:

	Nitrogen	Phosphorus
Domestic sewage	1,100-1,600	200-500
Industrial waste	1,000	----
Agricultural land runoff	1,500-15,000	120-1,200
Non-agricultural land runoff	400-1,900	150-750
Farm animal waste	1,000	----
Urban runoff	110-1,100	11-170
Rainfall directly on water	30-590	309

Nitrogen

By 1969, almost 6.4 million metric tons of nitrogen fertilizer were being used annually in the United States (11), a factor of seven greater than the 1950 figure. Because such fertilizers are highly water soluble, this extensive usage was quickly associated with enrichment-caused water pollution problems. However, available data do not often permit making true estimates of nutrient transfer from fertilizers to ground and surface water. As a consequence, both scientific and semi-popular literature are replete with divergent claims. A comprehensive evaluation of these conflicting claims requires consideration of the balance between nutrient inputs (from soil and fertilizers) and outputs (crop removal, erosion losses, leaching losses, volatilization, and immobilization) as affected by cropping system, soil conditions and management, and climatic factors (11)

Major factors in rural runoff are amounts of water applied and land use. The usual amount of nitrogen in runoff as reported by various writers ranges from 1 to 70 mg/1 (5). Although runoff is commonly thought of as the flow of water and entrained materials across the soil surface, other forms include irrigation return flows and effluents from tile drainage systems. Also included should be interstitial flow, or water that moves laterally through the soil between the surface and ground water level and results in a large part of natural stream flows when surface runoff is not evident.

Contributions of nitrogen contamination to ground water could occur under irrigated conditions if fertilizer and water application rates are high and tile drainage is not provided, or if the soil water level is allowed to fall below the level of the tile drains. In southern California, where citrus groves are fertilized annually with at least 36.8 kg/ha (200 lbs/acre) of N and irrigated with 0.03-0.05 meters/ha (3-4 cu ft/acre) of water, some well water nitrate values as high as 30-40 mg/1 have been reported and many wells have shown an increase in nitrates since 1950.

In 1972 in Illinois, the legislature considered the need to control the agricultural use of fertilizer through law (1). This may be the first "straw in the wind" indicative of things to come. It therefore behooves the scientific community to establish a technically sound library of facts upon which sound legislation can be based. The recent availability of N^{15} depleted nitrogen from which fertilizer formulations for experimental use is manufactured permits the first indisputable materials balance studies to be made that should reveal the true contributions of nitrogenous fertilizers to both surface and ground waters.

Phosphorus

About 1.7 million metric tons of phosphorus was used in fertilizers in the U. S. in 1969, approximately twice the amount used in 1950. The average annual rate of application on U. S. crop land is close to 3.6 kg/ha (20 lbs/acre) (11). The usual concentration found in runoff from agriculture land is 0.05-1.1 mg/1.

When applied to the soil in fertilizer, phosphorus is rapidly immobilized by adsorption on clay or precipitation as iron or aluminum phosphate (11). Therefore, vertical movement of phosphate to contaminate ground water is normally not a problem. Fertilizer phosphorus enters surface water in large amounts only with eroded soil. Its availability under these conditions to stimulate eutrophication is not well understood.

Control

Water quality degradation resulting from the employment of pesticides and fertilizers in agriculture is classified as non-point source pollution because it rarely produces a confined effluent treatable by engineering methods developed for collectable wastewaters. Therefore, preventive management is the preferred method for correcting and avoiding pollution by the runoff and percolation of agricultural chemicals.

Of the many factors that determine if an agricultural chemical will create a pollution problem, a few are subject to manipulation for pollution prevention. These are man's activities, including farming practices and the tailoring of chemical formulations for usage under various local conditions not subject to man's control (soil types, climate, topography, etc).

Future management of non-point source agricultural pollution will depend upon our ability to predict, for special agricultural practices, the probable pollution load that will enter watercourses within local drainage basins. Such management practices will be part of a system of area-wide waste treatment management plans, including those for urban-industrial concentration centers, which are required under provisions of the Federal Water Pollution Control Act Amendments of 1972.

As a step toward improving our predictive capability, the Southeast Environmental Research Laboratory of EPA, in cooperation with the Southern Piedmont Conservation Research Center of USDA, has embarked upon a research program to develop mathematical models that will allow the use of computer technology for simulating the results of any given combination of management practices insofar as the runoff and ground water pollution are concerned. These models will enable stream loading contributions to be forecast and agronomic practices to be selected that will not result in water quality degradation.

Other research is underway that will also improve our ability to understand and correct past environmental abuses. One of the most significant is the development of alternative methods for pest control, i.e., methods requiring minimal use of chemicals and maximum use of natural controls. This work is funded jointly by EPA and USDA through the RANN Program of the National Science Foundation.

The energy crisis is serving to further stimulate the above efforts. The current shortage of chlorine for manufacturing the troublesome chlorinated organic insecticides may accelerate the shift away from the use of these compounds. Inadequate supplies of chemical fertilizers are expected to stimulate farm practices designed to assure maximum utilization by crops and minimum vertical movement and runoff losses. The increased cost of fertilizers already is stimulating research to develop slow-release and other formulations designed to maximize efficiency.

Summary

Out of two decades of experience with water pollution problems associated with the agricultural use of pesticides and fertilizers, an understanding of the extent, causes, and effects of the problem and measures for its control are gradually evolving. Pesticide pollution in water is widespread at concentrations generally less than 1 ug/l. However, harmful biological effects are not precluded simply because the concentration is low.

The picture is not so clear concerning plant nutrients used in agriculture, largely because of numerous non-agricultural sources of pollution. The recent availability of N^{15} depleted nitrogen for research purposes will permit rapid advances in the status of knowledge concerning the true significance of nitrogen fertilizers as water pollutants.

Management of agricultural practices, coupled with developments expected in the manufacture of pesticides and fertilizers, is the key to the control of pollution by agricultural chemicals. Current research is aimed toward developing mathematical models to predict the pollutional impact of various farm management alternatives through use of computer technology as well as toward developing methods of pest control that are alternatives to use of pesticides. Industry, stimulated in part by the energy crisis, is expected to place increased emphasis on developing improved agricultural chemicals formulations. The energy crisis and higher cost of these chemicals will in turn stimulate use of better conservation practices.

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Chapter 14

THE INFLUENCE OF AGRICULTURAL AND FORESTRY INDUSTRY MANAGEMENT ON WATER QUALITY AND QUANTITY

John F. Gerber[1]

Agriculture and forest management affect water quality by influencing: 1) the material in suspension, usually clay and silt; 2) the plant nutrients in solution; and 3) the pesticides or their residues in solution or suspension. Animal production adds the animal waste problem. Water quality is usually defined in terms of maximum allowable concentrations (3). This useful approach usually considers only the materials which are currently troublesome in water quality.

Water that accumulates from rainfall intercepted on agricultural or forestry land is generally of high quality since it occurs in rural areas away from industrial air pollution and thus contains fewer dissolved chemicals such as sulfuric acid, ammonia, etc. Waters which drain from such land, however, may contain heavy loads of silt, clay, and organic chemicals such as tannins and other organic acids. These materials may occur naturally or be the result of man's management. Alluvial flood plains and heavy deposits of peat and organic soils are mute evidence to the natural occurrence of these processes.

All natural waters contain chemicals in solution and particles in suspension. The climate has a distinct and even in some cases an overriding effect upon water quality. Rainfall contains both particles and chemicals. Much of the natural nitrogen in the soil accumulated from nitrates in rain. Sodium, nitrates, chlorides, sulfates, and a few other chemicals are common constituents of rainwater. Surface waters that accumulate in climates where evaporation exceeds rainfall become enriched in these chemicals by the natural process of concentration. Silt and other particles in suspension carry large amounts of both tightly and loosely held chemicals which are swept away by surface runoff. The fate and eventual location of these suspended materials are determined by the topography, the soil type, the plant cover, and the intensity and distrubution of rainfall. Evaporation, the gradients of the stream beds, the temperature of the water, the depth of the water, and the aquatic plants present in streams and lakes all influence the suspensions that eventually accumulate in the larger water bodies of hydrologic systems. Very small and highly dispersed particles such as clays and colloidal amorphous materials remain in suspension for an extremely long time. The acidity of the water, the turbidity, and the dissolved chemicals have much control over the plants that live in the water, the amount of chemicals that they remove, and the suspended particles removed by precipitation or broken down by biological oxidation.

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Most organic materials in water that arises from forestry and agriculture are broken down by natural biological processes to carbon dioxide, water, and other innocuous natural occurring constituents. If this organic load becomes too great, or the flush of nutrients too large, the process is overloaded. The results are high oxygen tension and anerobic conditions which may result in fish kills. Released nutrients stimulate growth of aquatic macrophytes and algae. Water quality declines with a change in the fish populations, sometimes an increase in total game fish production, but almost always an increase in non-game or rough fish.

The soil-plant complex is an effective nutrient uptake and recycling system. As water passes through the soil past the plant roots many of the nutrients are removed. These nutrients, retained by the plant system, cycle through the forest, but are partly removed by harvest of annual crops. Some plant nutrients which pass beyond the rooting zone are retained by fixation in the soil, especially phosphorus that forms chemical complexes with calcium, aluminum, silicon, and iron. Most of the phospho-alumino-silicates and ferric alumino-silicates are extremely insoluble and are effectively removed from the water system. Nitrate nitrogen is the most troublesome single plant nutrient in agricultural and forest systems. Most forests are not fertilized or only with small amounts of nitrogen and phosphorus, but even then only a portion of it is retained (8). Agronomic and horticultural crops are much more efficient in removing nitrogen, but since larger amounts are needed for economic production drainage water from cropland contains more nitrates than from forest lands(4,5). It has been estimated that three to five pounds of nitrogen are added per acre of soil per year by rainfall (10). Accumulation over the years has resulted in a sizable amount of nitrogen cycling through forest systems and through the organic matter. The exact nature of the nitrogen cycle remains an enigma because of the denitrification and nitrogen fixation by a host of microorganisms. Even without fertilization, nitrates and phosphates have accumulated in forest and agricultural soils so that native or natural drainage from these soils contain measurable quantities of nitrates and phosphates (9,2).

Management of agricultural and forest systems and the use of technology has a large impact on water quality. Most of the soils in the southeastern United States would be judged to be relatively infertile (9). Successful agriculture and forestry or at least intensified agriculture and forestry is highly dependent upon the use of chemical fertilizers to increase productivity. In much of the low, poorly drained areas of the southeastern United States, especially the coastal regions, the soils are sandy with low cation exchange capacity and high water tables. Erosion is not a serious problem, but added fertilizer nutrients are in close proximity to the water table. The upland soils of this region are in many cases subject to erosion unless adequate water management is used and a good plant cover maintained.

Because of the impact of management upon water retention, water quality, and runoff, watershed management and research have occupied a prominent role in agricultural and forest investigations in the southeastern United States. In the upland areas attention has been centered upon erosion control which increases the quality of water by removing suspended sediments and the storage by infiltration and surface retention. In the low coastal regions much of the attention has been devoted to water control which includes in almost all cases drainage and irrigation. Almost all of the intensive agriculture in Florida with the exception of the central sandy ridge is possible only because of careful water control and drainage. Even forest plantations are commonly bedded to improve drainage of the rooting zone during wet periods. This drainage of land for agricultural and forest purposes gives rise to a conflict of interests between the urban water user and the agricultural water user. In part this conflict is exemplified by the channelization of the Kissimmee River and the utilization of much of the former flood plane for agricultural pastures. Water control for agricultural purposes usually reduces the amount of water stored in the profile, increases the stream velocity by removing obstacles from the channel, and straightening and deepening it. It is felt by fishery biologists and ecologists that this process reduces water quality by eliminating slow meandering of the stream through native shallow areas where plants could remove nutrients from the water. Whether this process significantly changes the water quality is a matter of some debate because few records of water quality were kept prior to the channelization of most streams.

Since both agriculture and forestry depend upon water for plant growth there is a management effort made to retain sufficient water to insure plant growth either by irrigation or by careful water control. Many native forest areas have virtually no water control other than bedding of some areas used for pine and avoidance of ponds and bogs. The effects of bedding for water control in forestry have been marginal in terms of tree growth and productivity but have increased the survival of planted pines.

Drainage causes aeration of soil profiles that were normally anerobic producing oxidation and the release of nutrients held in organic matter complexes in the soil. As a consequence the drainage of soil for agriculture and forestry leads to an increase in the nutrient content of drainage water even though fertilizer may not be used. The drainage of organic soils, especially those adjacent to lakes, for agricultural purposes produces rapid oxidation, in Florida a rate equivalent to the loss of approximately one inch of soil per year, with the concomitant release of nutrients, especially nitrates and phosphates. The release of nitrates and phosphates contributes to the native fertility and high productivity of such soils but also contributes to water quality problems. In Florida we are investigating the possibility of recycling drainage waters from organic soils through recycling ponds rather than returning these waters to surface streams and lakes. Even though drainage water may be higher quality than lake water into which it is discharged, subsequent evaporation leaves behind the plant nutrients. The result is a hastened process of natural enrichment by transferring nutrients that had been slowly cycled in the organic debris in lake bottoms into the water by increasing the cycling rate. Fertilizer nutrients added to such soils may reach receiving waters, but their contribution is so small in relation to the total quantity from the oxidizing soils as to be virtually insignificant.

Burning pastures, range, and forests to prevent wildfires and as habitat or range management influences water quality. While hard data are scarce the fires hasten recycling of nutrients. Nutrients present in the ash include phosphorus, potassium, calcium, and magnesium. Nitrogen is lost in gaseous forms. Heavy rains following burning can cause a flush of nutrients into receiving waters or into the deep soil profile. Burning of slash following clear cutting or in site preparation has a similar effect. In the management scheme burning may be an essential tool used to increase the productivity and change the composition of native range and forest, to improve wildlife habitat, and to control the understory and species competition of woodlands. Control burning abates wildfires which can cause serious erosion.

Clear cutting, logging, site preparation and wildfires of range and forest lands all contribute to the sediment load in streams.

Even so, only 5 to 10% of the 4 billion tons of sediment washed into tributaries and streams annually comes from forest land (9). Erosion is a serious problem on 180 million acres of cropland and a secondary problem on another 50 million acres. Geological erosion accounts for about 30% of the sediment in streams. Most geological erosion originates in the less humid regions of the United States and is not a large source of sediment in the southeastern United States.

Research has shown that plant cover is a major deterrent to erosion. Extensive watershed research on watershed characteristics has lead to the development of predictive runoff and erosion equations based upon soil characteristics, slope, cover and rainfall intensity. Utilization of high-speed digital computers has permitted the development of a universal erosion equation and watershed models of runoff and retention (11).

Improved forest management and technology in logging such as use of helicopters and overhead trams and construction of forest roads has reduced erosion from woodland harvest. Wildfire abatement and prevention of overgrazing of range lands have helped to further reduce serious erosion. Contour cropping, close planting, terracing and minimum tillage can reduce erosion from cropland. Surface sealing, nonwetability, and the fundamental physics of soil particle detachment and movement are basic phenomena which influence infiltration, runoff, and erosion. Settling or silting basins can be used to decrease sediment discharged into streams.

Nutrients lost from the soil, primarily phosphorus, nitrogen, and in some cases potassium, either reach surface water or ground water aquifers. The over-enrichment of surface waters is termed eutrophication and usually leads to the growth of algae and aquatic weeds. Algae blooms produce unpleasant odors and bad tastes in potable water.

Surface runoff from forest and agricultural lands may contain both nitrates and phosphates. Drainage from such soils usually contains less than one part per million of phosphate (4). Nitrates may be present in drainage waters, especially in sandy soils where large amounts of nitrogen fertilizers are used. Evidence from the midwest indicates that very little if any of the nitrates in ground water originates from fertilizers (10). In semi-arid and sandy soils or soils with high percolation rates fertilizers can contribute to the nitrates in the aquifer.

Fertilizers play a major role in cropland, and research conducted under the CRIFF Program (6) in Florida indicate that fertilizers, phosphorus and nitrates especially, may become a major component of the forest program in the southeastern United States. Rates of nitrogen application are low in terms of cropland. Application of phosphorus is used each 5 to 40 years depending upon the rotation length. Rates of application used are about 35 Kg of phosphorus per hectare. Nitrogen is used at about the same rate, but may be repeated more often. The anticipated effect of these fertilization rates upon water quality are thought to be minor, but since large acreages are involved and since the uptake efficiency of trees is reported to be low (7) it is hard to predict the results. Management of water influences quantity primarily as it interacts with the climate and affects water infiltration, retention, and balance between evapotranspiration and rainfall. The yield of water from a given watershed depends upon the balance between rainfall and evapotranspiration. The difference occurs either as surface runoff or as storage in the deep soil profile which eventually becomes a part of the ground water system. Since the southeastern United States is a humid region more rainfall occurs than evapotranspiration, although in certain local areas such as southwest Florida the balance is nearly equal or slightly negative.

Evapotranspiration depends upon the solar energy available from the sun, the crop density, the water storage capacity of the soil profile in the rooting zone, and the rainfall amount and distribution. If a crop canopy is closed the evapotranspiration approaches a maximum. Further increase in the number of stems or the number of plants per unit area usually does not produce an increase in evapotranspiration. Individual crops demonstrate differences in the evapotranspiration rate which are apparently related to the characteristics of the plant. Generally, evapotranspiration will range from 35 to 45 inches in the southeastern United States depending upon the crop, the soil, and the rainfall.

Management produces an influence upon the quantity of water which a watershed will yield by affecting the soil moisture storage in the profile, the retention of surface water, and the influence that planting rate and crop type has upon evapotranspiration. If irrigation is added, a complicating factor is presented because it in effect redistributes previous rainfall.

The largest water yield from a given area can be obtained if it is fallow. This of course ignores the adverse effects that may occur in terms of erosion and runoff. Any plant cover transpires and reduces the amount of water that can be harvested from the watershed. Stand density, species characteristics, and surface characteristics as well as the understory of forests all have an important but subtle effect as compared to clearcutting. Slash accumulation on the forest floor in uplands can increase the water yield by retention of water in the debris. This increases infiltration and decreases surface runoff.

Fertilization probably has a minor influence upon water yield except as it controls the accumulation of materials on the surface and ground cover which retard runoff.

Runoff rates strongly influence stream flow, flood flow, and sustained flow. Infiltration is closely tied to runoff. Surface retention of water on soils with low infiltration rates can be controlled by the surface cover which is in turn influenced by management. Management practices which retain a good surface cover will reduce the maximum discharge into streams, produce runoff over a longer period of time, and by retaining water in contact with the surface of the soil increase the amount of water that is infiltrated. By reducing the impact of raindrops covers may change infiltration rates. Drainage for forest and agricultural reasons tends to reduce surface storage, storage in the profile, and storage in shallow ponds, swales, and swamps. However, it may be necessary to prevent floods, provide storage during drought, and improve the site for production of forest and agricultural crops.

Agricultural and forestry plant debris represent a huge biological oxygen demand that is in excess of that produced by municipal sewage. However, since this debris is usually distributed over the land there is little immediate effect upon streams and water quality unless the material is deliberately placed in tributaries or is concentrated locally. The manufacture of forest products, especially lumber and paper, often leads to water qualtiy problems which are essentially of an industrial nature and not particularly a part of the agriculture and forest production industry. Paper pulp processing is especially troublesome since in addition to organic debris from the woods spent chemical liquors are produced which must be either recycled or removed in order to prevent water pollution. This is a troublesome and continuing process, but since it is of a point source nature is amenable to engineering solutions(1).

Summary: The adverse effects of forestry and agricultural management upon water quality are largely through increasing sediment loads of streams and tributaries by erosion, contributing chemicals primarily from agricultural fertilizers and pesticides to the stream and ground water and by management practices including burning, clear cutting, logging, drainage, and improper water management. Almost all of these practices can have a beneficial effect if conducted properly. Erosion control can be obtained by using good cultural and management practices. Intelligent use of fertilizers can increase tree growth and is vital to intensified agricultural production. Pesticide problems are of sufficient magnitude to deserve a special special attention and are beyond the immediate scope of this paper. Management practices such as clear cutting and burning have been shown to increase both water yield and quality if conducted properly. Logging and selective cutting can be conducted by the use of good technology to prevent the loss of ground cover and subsequent increase runoff and erosion. Water management and especially drainage are difficult problems to manage for the mutual benefit of all interests. In most cases alternative solutions will probably be found for water quality and quantity problems produced by drainage. Some of the desirable characteristics of water management from an urban standpoint are mutually exclusive of those for agriculture and forestry, but in many instances mutually beneficial management practices can be devised which benefit all of society.

Research Needs: The research needs to improve the quality and quantity of water as it is related to agricultural and forestry management are currently being studied by task forces of State Agricultural Experiment Stations, the USDA-ARS, the Forestry Service, the Economic Research Service, and various other agencies of State and Federal Government. A few obvious items which need attention are the effects of fertilizer upon water quality, the effects of clear cutting and range management upon water quantity and quality, the effects of various methods of harvesting technology upon water quality, the effects of disposal of slash following forest harvesting, the effects of water management and drainage upon water quality and quantity as well as improved methods of erosion control. The use of fire in the forest system has been studied rather intensively at Tall Timbers Research Station and there have been several proceedings of Tall Timbers fire ecology conferences. The fundamental relationships between water use in evapotranspiration, the energy budget of the surface, and the control of transpiration by forest trees has been investigated to determine the effects that modification of transpiration or the energy budget might have upon water yield. This area probably needs further attention even though there are energetic reasons which may limit the role that management can play in modifying the water budget. There are other important research areas, but these have occurred to me in the preparation of this paper as those which are deserving of attention. Water quality and quantity will become an increasing area of overlapping concern between urban and non-urban dwellers in the southeastern United States in the coming years. An understanding of the effects that agricultural and forest management have upon the water system and upon the urban dweller would help in the resolution of potential conflicting problems.

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Chapter 15

USE OF MUNICIPAL WASTEWATER AND SLUDGE ON AGRICULTURAL LAND

David W. Hill

ABSTRACT

The principal dangers of applying municipal wastewater and sludge to agricultural lands for crop production are the transmission of pathogens and the build-up of heavy metals in both the soil and crops. Examples of current practices are given to illustrate both problems and successes of land application. Particular attention is given to the Penn State successes of municipal wastewater application to both forested areas and cropland, and to the Chicago project in which digested sludge is being used to produce crops on recently strip-mined land. A plea is made for an open-minded approach to land application under appropriate circumstances as both a nutrient conservation measure and as an often practical solution to wastewater treatment and sludge disposal needs.

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INTRODUCTION

The current U.S. population of 212 million people produces in excess of 12.5 billion gallons per day of domestic wastewater.* Assuming treated wastewater concentrations(17) of 20 mg/l total nitrogen (valued at 21¢/lb N)(25), 10 mg/l total phosphorus (valued at 15¢/lb as P_2O_5)(25), and 14 mg/l total potassium (valued at 6.3¢/lb as K_2O)(25), this wastewater represents a yearly value approaching $25 million. If nutrients from the industrial load typically present in municipal sewage are included, the nutrient value of the waste is more than doubled. In this day of short fertilizer supplies and severe over-enriching of our water resources, using these wastes to make the soil productive makes sense. Why dispose of them into our waterways, where their most valuable attributes cause harm? Moreover, land application, especially where there is no subsequent discharge to waterways, is in conformance with the stated "goal" of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500; Sec. 101(a)(1):

> "that the discharge of pollutants into the navigable waters be eliminated by 1985."

In some locations where a high degree of purification is required, land application or soil treatment systems with a discharge have been shown to be far more economical than conventional treatment works plus the necessary advanced waste treatment processes. Stevens estimates that the soil treatment system for Muskegon, Michigan, is "able to treat one million gallons of wastewater for about $90, or about half the estimated cost of equivalent advanced waste treatment."(22)

The capital cost of the system ($36 million) "is slightly more than comparable conventional and advanced facilities of equivalent capacity," but the low operating costs make it much less expensive over the long run. This particular soil treatment system has several other advantages:

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* Based on 60 gallons per capita per day of domestic use.(16)

- it is less susceptible to failure following accidental spills of toxic materials;
- it is more flexible in handling sudden increases in daily flows, and
- full treatment can be achieved for flows up to 88 million gallons per day (mgd) compared to 67 mgd for the comparable activated sludge system.

Costs for other systems are indicated in Table 1.

The present discussion will focus primarily on the problems associated with land applications of municipal wastewaters and sludges for the production of crops and on the effectiveness of such practices. The emphasis is on pathogenic, and especially heavy metal problems. The following five reports, supplemented by the bibliographic references, contain the most information concerning the use of wastewaters in agriculture:

- Wastewater Management by Disposal on the Land,(19) by the Corps of Engineers, is a thorough review of the physics, chemistry, and biology of land disposal and related environmental effects.
- Green Lands - Clean Streams,(22) by the Temple University Center for the Study of Federalism frankly advocates land application in a very informative discussion of principles and examples of the practice.
- Recycling Municipal Sludges and Effluents on Land(8) is the proceedings of a symposium involving many experts in waste treatment, soils, agronomy, and especially land application. Discussions following each paper are printed and often reveal related topics, problems, and opinions that are not otherwise available.

TABLE I

COSTS OF LAND DISPOSAL

Project	Comments and Costs
Santee County Water District, Southern California	For no more than the cost of ocean disposal through the San Diego system, the Santee project provides five lakes, water recreation facilities used by hundreds of thousands of patrons, and irrigation of a golf course. (22, p. 62)
Bakersfield, California	Since 1912; irrigates 2500 acres with municipal wastewater; \$47.98 per million gallons. (22, p. 75)
Golden Gate Park, San Francisco, California	One mgd provided to 1,013 acre park for irrigation, lakes, and waterfalls, for \$70.00 per million gallons. (22, p. 77)
Campbell Soup, Paris, Tennessee	Treats food processing wastes through overload flow, produces Reed canary grass hay. Operating costs only average \$52.00 per million gallons. (22, p. 114)

- Wastewater Treatment and Reuse by Land Application, Volumes I and II,(17 and 18) prepared by Metcalf & Eddy, Inc. for the Environmental Protection Agency is concerned with engineering development of land application systems. Volume I is a general summary, whereas Volume II presents more detail.
- Survey of Facilities Using Land Application of Wastewater(23) is a report of an American Public Works Association field survey of 100 land application facilities complete with color photographs of representative practices.

MUNICIPAL WASTEWATER AND SLUDGE ON AGRICULTURAL LAND

The problems encountered in the use of waste materials onto agricultural land depend on the specific kind of nutrient that is applied. Only domestic and municipal wastewater-related materials are considered here:

- Untreated wastewater (raw sewage)
- Raw or untreated (primary) sludge
- Treated wastewater (both primary and secondary effluent)
- Digested sludge

Untreated Wastewater (Raw Sewage)

Direct land application of raw sewage is almost universally prohibited in the United States by state regulations because of the danger to public health. Pathogens can survive from about 12 days for Typhoid bacilli in loam and sand to six years for Ascaris eggs in soil.(18) The survival rates of viruses in soil are not well known although some evidence suggests that they are inactivated in soil environments.(18) Insect and rodent problems are intensified by the use of raw sewage.

In some countries, however, land application of raw sewage is fairly common. In India, 40 percent of the 550 mgd of wastewater produced by sewered communities is applied raw on 132 farms, involving 30,900 acres in all parts of the country.(23) In Argentina, the application of raw sewage to land is encouraged for reforestration projects in arid areas.(23)

In Mexico, the canal system draining Mexico City has long been receiving industrial and domestic wastewaters and providing irrigation water in El Mezquetal, Hidalgo.(23) The average quality of this mixture of treated and untreated wastewater at the point of use is shown on Table II. The great variety of crops shown on Table III, grown in response to market demand, includes many root crops and others likely to carry contamination. The sewage has not been found to be toxic to these crops and health problems, if any, are apparently of no concern. Within Mexico City itself five secondary treatment plants treat five cubic meters per second (114 mgd) of municipal wastewater. The effluent is chlorinated and used within the city for irrigation of parks, playgrounds, and other large public areas as well as for fountains and park lakes. These treatment plants are operated only during the dry season (November through May) and the sludge solids removed are discharged to the untreated canal flow.(23)

Raw or Untreated (Primary) Sludge

Direct application of these sludges is also such an obvious health hazard that it is seldom considered in this country. However, Ferrell and coworkers(9) reported that raw sludge may be stabilized by adding lime (the familiar procedure for army latrines) to a pH near 12, providing a high level of both bacterial and viral disinfection. The routine need for lime on agricultural soils might make this a useful practice if it

TABLE II

IRRIGATION WATER QUALITY
AT EL MEZQUETAL, MEXICO(23)

Parameter	Concentration in mg/l
BOD	244
DO	0.4
COD	228
Total Solids	1,623
Total Dissolved Solids	1,209
Suspended Solids	411
Nitrogen	
Organic	1.9
as NH_3	15.7
NO_2	0.015
NO_3	0.2
Alkalinity as $CaCO_3$	472
Carbonate	9
Bicarbonate HCO_3	555
Chlorides	236
Sulfate	95
Sodium	321
Calcium	43
Magnesium	22
Boron	0
ABS	12.4
pH	8.0 units

TABLE III
SUMMARY OF AGRICULTURE PRODUCTION(23)
1971-1972
03 IRRIGATION DISTRICT – TULA HIDALGO

Crop	Crop	Hectares	Metric Tons
Alfalfa Verde	Alfalfa	12,396.40	1,181,376.920
Ajo	Garlic	94.50	258.456
Arvejon	Peas (large)	12.89	20.820
Avena Verde	Green Oats	2,998.75	54,426.714
Calabacita	Squash (small)	674.33	7,282.764
Cebada Grano	Barley Grain	1,865.43	3,645.410
Cebada Pago	Barley (forage)		4,059.874
Cebolla	Onion	23.79	168.909
Cilantro (semilla)	Parsley Seed	3.53	4.589
Col	Cabbage	27.95	501.843
Chicharo	Peas	1.00	7.900
Chiles Verde	Green Hot Peppers	768.80	8,231.350
Flores	Flowers	10.41	
Frijol Grano	Navy Beans	1,259.02	1,563.870
Frijol Ejote	Am. String Beans	58.30	151.580
Espinaca	Spinach	0.82	9.020
Frutales	Fruit Trees	25.08	213.180
Girasol	Sunflower	37.19	230.578
Haba	Lima Beans	95.84	1,990.070
Jitomate	Am. Tomato	1,554.65	49,437.870
Lechuga	Lettuce	74.47	1,457.764
Maiz Grano	Corn (kernels)	17,053.60	70,260.525
Maiz Rastrojo	Corn (forage)		65,179.023
Maiz Verde	Corn (sweet)	101.20	7,084.000
Nabo Forraje	Forage Turnips	112.37	1,011.330
Melon	Melon	1.00	7.100
Pepino	Cucumber	34.74	166.752
Pradera	Meadow Grass	12.80	2,080.000
Tomate	Tomato	216.90	2,051.706
Trigo Grano	Wheat Grain	7,293.79	13,865.494
Sandia	Watermellon	0.40	3.960
		46,809.95	1,476,749.371
		Acres	**U.S. Tons**
		115,620.65	1,624,424.30

Note: 1 metric ton = 1.1 (U.S.) tons
1 (U.S.) ton = 0.907 metric tons
1 hectare = 2.47 acres

Note: The crop hectares listed are more than the hectares of land available since a second crop in some instances has been produced on the same land.

were not for the problem of Salmonella regrowth in the soil. Walker of USDA in Beltsville, MD, reported(24) that after limed sludges were mixed with the soil, the pH dropped and Salmonella organisms were found even where the sludge was treated at the highest lime level.

Lime is apparently unable to penetrate to the center of all the "clumps" of infected material. When the pH drops in the soil, the putrescible material provides an ideal growth medium for the surviving bacteria.(3)

Treated Wastewater (Both Primary and Secondary Effluent)

Treated wastewater at least has the solids removed and may contain a few less pathogens than raw sludge, but it is far from clean. Aerosols from sprayed sewage, both raw and treated, present a potential public health hazard to the surrounding countryside.(13) Merz(15) concluded, however, that travel of viable bacteria is limited to the area covered by the sprinkler mist. Dessication appears to be a major factor in bacterial die-off.(18) The extent to which viruses are spread by aerosols is not known. Low trajectory nozzles, especially downward sprinklers such as are designed for the travelling rigs of the Muskegan project, should greatly reduce the potential hazard from aerosols.

Adequate disinfection, of course, greatly reduces the dangers of aerosol contamination. In the Muskegan project disinfected secondary effluent flows through open channels to allow for dechlorination by air contact before reaching the two irrigation pumping stations. Without this dechlorination, the irrigation water could be toxic to microbial activity in the soil.

Isreal, which has perhaps done more than any other country to make the most use of her water resources, allowed a great many uses of treated effluents -- provided prescribed separations were maintained from public areas. After the 1970 cholera outbreak, however, the Israeli government has prohibited the use of effluents on food crops and is studying its wastewater irrigation regulations.(23)

The danger of gradual heavy metal accumulation in soil over long periods of use has been cited many times as an objection to effleunt irrigation. This problem, also created by raw wastes, is a more obvious problem for irrigation with digested sludge and will be discussed in more detail later. Effluent irrigation operations with long histories of use have not given rise to problems with heavy metal. The Paris and Berlin sewage farms, begun in 1885 and 1895, respectively, have shown no metal problems except for a manganese deficiency at the Paris farm.

The Penn State Project

A system at Penn State University(22) was begun to alleviate both pollution of a popular fishing stream and the effects of a long-term drought. Secondary municipal effluent was diverted for irrigation of both farm land and wooded areas.

Research at Penn State has shown "that soils are capable of removing unwanted phosphorus from the effluent for 'countless years without becoming oversaturated.'"(19) Ten years of irrigation with 472 inches of sewage effluent did not increase phosphorus concentrations below the 12-inch depth in a medium-textured clay loam. Phosphorus concentrations in the soil at four feet (0.05 to 0.07 mg/1) and in groundwater (0.04 mg/1 and less) were virtually unaffected.(22)

In the Forest Area, detergent residual (Methylene Blue Active Substance [MBAS]) was reduced an average of 55 percent while moving through the forest floor and from 38 to 81 percent while percolating to the four-foot depth. Nitrate-N was reduced over the first year by 68-82 percent in the first foot of soil, but this reduction decreased over the next seven years to only 0.57 percent removal at four feet. Over the long term, therefore, nitrate removal at those application rates was poor. Whether or not denitrification occurs at deeper levels in the soil has not been determined. Other elements decreased while percolating to the four-foot depth to the following extents:

- potassium by 82.8 percent,
- calcium by 51.9 percent,
- magnesium by 66.7 percent, and
- boron by 67.6 percent.(22)

Boron retarded the growth of red pines, but did not adversely affect other forest species studied.

Wastewater renovation in the Agronomy Area was not directly measured, but crop analyses showed that plants were extracting from the soil as much or more nitrogen than was applied in the sewage. Removals were dependent on the type of crop as follows:

Macro Nutrient	Crop		
	Corn Silage	Alfalfa Hay	Reed Canary Grass
N	110 #/A	284 #/A	2073 #/A
P	18.9 #/A	33.6 #/A	--
K	102 #/A	300 #/A	--

On the average, crops extracted the following elements in the indicated percentages of the amount applied to the soil in the wastewater:

Element	Removal
K	118%
Ca	19
Mg	11
Na	0.4

Sodium was obviously not removed by the soil system.

Groundwater from on-site wells was of better quality than water from off-site domestic wells and springs. Concentrations at on-site wells remained comparable to pre-irrigation conditions:

Groundwater Quality	
Substance	mg/1
MBAS	0.08
N	0.7
Cl^-	5.93

Based on the very effective wastewater renovation brought about by the combination "living filter" and soil adsorption, Penn State is expanding its land treatment capacity from 0.5 to 4 mgd, which will handle 100 percent of the University effluent together with 90 percent of that from the borough of University Park.(22)

The Penn State system represents better than most a detailed monitoring of land application effects. However, it is only one of a host of land application systems in the U.S. The 100 sites surveyed in the recent EPA publication of an APWA study, Survey of Facilities Using Land Application of Wastewater(23) are only a fraction of the 571 surface application systems identified in EPA's 1972 Municipal Wastewater Facilities Inventory.(18)

Digested Sludge

For years the city of Milwaukee has been bagging and selling a fertilizer-soil conditioner called "Milorganite." It is nothing more than digested and dried sewage sludge, which is naturally rich in nutrients and organic material that is biologically degraded to humus.

The main problem with using digested sludge on agricultural land is its high concentration of heavy metals, which are toxic to both crops and people in high concentrations. Like phosphorus, the metals are retained in the upper soil by the high ion exchange capacity of the soil. The removal of metals by the soil may help to protect our water resources, but it may also poison our agricultural topsoil. Soils have been poisoned by heavy metals, not by the use of sludge, but by the use of arsenical fungicides in Washington state orchards. Arsenic accumulated to such levels over the life of the orchard that, when the orchard had to be replanted, all the topsoil had to be scraped up and removed in order to expose soil in which new seedlings would germinate.(13) However, a facility near Herefordshire, England, has been irrigating with liquid digested sludge containing about three percent solids for over 20 years with no apparent problems from heavy metals. The success of the operation is shown in a non-technical 16 mm color film entitled Wealth from Waste.(21)

Blood, in the NAAS Quarterly Review (4) described metal toxicity problems to metal-sensitive sugar beets grown on a sludge and effluent-irrigated sand having a low pH. The problem was easily overcome by liming, but it could recur with a subsequent pH drop.

Tables IV and V show typical sludge properties.

TABLE IV

HEAVY METALS IN SLUDGE (1971-1973)(6)

Element	Literature*	Atomic Absorption**
Cd	61 mg/l	93 mg/l
Cu	906	1,840
Hg	14.5	3.2
Ni	223	733
Pb	404	2,400
Zn	2,420	6,380

* From about 100 references
** From 80 additional samples

TABLE V

NUTRIENTS CONTAINED IN DRY SLUDGE SOLIDS(6)

Total N	35,000 - 64,000 μg/g
Organic N	20,000 - 45,000
P	8,000 - 39,000
K	2,000 - 7,000

Sources of Heavy Metals in Digested Sludge

Heavy metals in sewage sludge digesters have long been blamed for digester upsets, and the metal plating industry has usually been pointed to as the culprit. However, there has been a growing realization lately that heavy metals in sludge are fairly ubiquitous. McCarty, in outlining a bioassay procedure to determine the precise cause of digestive upsets,(14) cautioned that the mere presence of heavy metals does not identify them as the cause of upsets. "If you look for heavy metals in a digester, you'll find them."

Kaplovsky of Rutgers University, reported(11) on a study of five separate digested sludges containing no industrial waste in Ocean County, New Jersey. In comparing these with a series of analyses he had gathered as Director of Research at the Chicago Metropolitan Sanitary District, he found that the concentrations of all heavy metals were in the same order of magnitude in the domestic waste as in the more industrial waste found in Chicago -- and Chicago has a predominance of metal plating industries. He mentioned zinc, copper, lead, and cadmium as being especially high in the domestic sludge.

Robert Dean(6) reported on a New York study in which about a third of the copper in New York City's wastewater was found to come from domestic plumbing, not from copper pipes but from corroding brass fixtures. Likewise with the zinc. Simply restricting discharges from plating plants will not solve the heavy metals problem.

Effects of Urban Runoff

Heavy metals in sludge from wastewater treatment plants receiving street runoff and washings through combined sewer systems may be greatly increased by "urban runoff." The Environmental Protection Agency's

Region IV, Surveillance and Analysis Division, obtained the following results for the first four samples of runoff in Peachtree Creek in Atlanta immediately following the start of an intensive thunderstorm. The predicted street runoff from the proposed development of North Fulton County by 1990 is based on other data.

Sample Sequence	Date	Concentration in μg/l						
		Zn	Ca	Pb	Cr	Cd	Ne	Hg
1	9/9,10/73	2550	375	2460	440	20	75	0.4
2	"	4400	500	4150	630	30	90	2.0
3	"	1380	230	1780	200	<20	40	1.1
4	"	1580	290	2080	860	<20	60	0.8
Prediction for North Fulton County, GA		348	210	240	35	10	67	73

The prediction for North Fulton County, Georgia, was developed by the authors and co-workers based primarily on projections on street surface runoff as reported to EPA by Sartor and Boyd.(20)

While these data do not relate directly to heavy metal concentrations in digested sludge, they do suggest that where street runoff forms a significant portion of the incoming flow, this may be a significant source of these metals.

The Chicago Project

The largest land application of digested sewage sludge is operated by the Metropolitan Sanitary District of Greater Chicago. The district is now barging, lagooning for six months, and then applying its digested sludge to a 7,156 acre tract of strip-mined land in Fulton County, Illinois.

approximately 180 miles southwest of Cook County, Illinois.(5) Pilot studies have been underway since 1967 and full scale applications since 1971. Corn, soybeans, and oats are the principal crops. Some increases of metals in crop leaves have been detected, but a 19-county state grain sampling survey has shown that the harvest from the Chicago Project lies within the normal range for the state.(12) Application amounts are limited by nitrogen -- by the ability of the crop to absorb enough nitrogen to prevent its percolation to groundwater. Phosphorus and some trace metals are supplied in excess of plant needs and are adsorbed by the soil. Penn State results suggest that potash and, depending on the crop, possibly a few trace nutrients are deficient for plant needs.(22)

These full scale results paralleled results of research conducted for the district and EPA at the University of Illinois. Jones and co-workers(10) found that soybeans grown on soils treated with sewage-sludge, or cadmium acetate, or various combinations of the two, absorbed and translocated cadium to aerial plant parts and to the seed. However, the cadium content of the seed was considerably below that in the total plant at harvest. Where only sludge was applied, the seed concentration remained at or below one ppm of Cd while the total plant concentration varied from 1.8 ppm Cd in the control to 18.5 ppm Cd at a 150 T/acre application rate. Intermediate applications of sewage sludge (50 and 100 T/acre) actually depressed the cadmium content of the seed below the one ppm level of the control. Zinc content in the seed, by contrast, "increased substantially and significantly with simulated and digested sludge treatments"(10) as shown by unpublished date.

These whole-plant results parallel the unpublished findings of Boswell,(2) who is growing fescue grass on land at Experiment, Georgia, fertilized with digested sludge from the South River Sewage Treatment Plant in Atlanta. (Like Chicago the Atlanta system is fed in part by combined sewers.) Zinc levels in both the soil and the fescue reached such high levels that he terminated sludge applications and is now monitoring persistence of the various metals in the sludge.

Dr. Cecil Lue-Hing, now Director of Research for the Metropolitan Sanitary District of Greater Chicago, feels that more sludge recycling projects should be undertaken(12) using land and crops chosen to minimize potential hazards. The district purchased 7,156 acres of strip-mined land from which soft coal had been removed. It is in an area in which mining operations have devastated 40,000 acres and are continuing to do so at the rate of 3,000 acres per year. Using sludge to grow crops on this land would not endanger valuable agricultural land. Moreover, the practice should give information about the long term problems or successes of sludge applications. As long as a good crop monitoring program is maintained, public health should be well protected.

Crop monitoring is the crucial factor. Dr. Dale E. Baker of Pennsylvania State University has cautioned against land application of sewage sludge because of the public health danger unless crops can be properly monitored.(1) He is part of a group developing a new monitoring approach to improve on the present cost of $200 per sample for metal and nutrient level analyses.

RESEARCH NEEDS

In order to improve the pool of existing knowledge and to develop safe and efficient land application-crop production systems, research should be focused on:

- A careful study of heavy metal and trace element build-up, distribution, and effects in soils and crops.
- A study of the spread and persistence of viruses carried in spray irrigation.
- Techniques to remove viruses prior to spray irrigation.
- Economical techniques for removing heavy metals from digested sludge and from raw sludge and wastewater.
- Variations in land application practices needed for various soil types, cropping practices, and climatic conditions.
- Evaluations of long term effects of those facilities with a long history of land application.
- Heavy metal and trace element analyses of crops produced on sludge-irrigated land.
- A comparison of heavy metals and trace elements in crops grown
  - near urban areas,
  - on recently stip-mined areas,
  - on land fertilized from different sources containing varying amounts of non-essential heavy metal contaminants, and
  - on land containing naturally high levels of various heavy metals and trace elements.
- The study of denitrification mechanisms within and below the root zone.
- The use of overland flow for municipal wastewater treatment using knowledge and guidelines developed at the several Campbell Soup Company plants.

CONCLUSIONS

Conclusions drawn in the rapidly developing area of land application of wastewater and digested sludge depend more on the investigator's personal outlook and vested interests than on established facts. Our understanding of the short- and long-term ramifications of sewage and sludge irrigation is incomplete; yet technology seldom, if ever, can wait for a perfection of its basic science.

A conservative person with a protective concern for public health might demand a moritorium on the practice until further controls of pathogens are developed and until the levels of heavy metals in crops and their significance to human health can be more fully determined. Fertilizer interests might view the practice as dangerous competition, as might small farmers in areas where big-city sewerage districts are buying land; and some agricultural interests view it as a threat to the long-term productivity of our crop land.

However, equally as much can be said on the positive side. As a society we are coming to recognize that wastes are simply resources out of place; the concept of sewage as useless filth is gradually changing. Treated effluents and wastewater sludge contain valuable nutrients with a demonstrable value for reclaiming land and increasing productivity of many crops. In water-short areas they constitute a vital water supply. Many studies suggest that natural barriers prevent dangerous heavy metal accumulations in grain, even when these metals are very concentrated in topsoils. The conservation-minded person finds this reuse-recycle concept very appealing and, in the absence of clearly defined hazards, would like to see it promoted. Individual farmers faced with a fertilizer shortage and/or a need for irrigation water tend to be very pragmatic about meeting these needs.

Perhaps the greatest need of all is felt by those charged with managing urban sewerage districts. Costs are skyrocketing and environmental demands are becoming increasingly stringent. Land application following conventional treatment often appears to offer the best answer for both problems: costs, even with elaborate monitoring and built-in environmental safeguards, are sometimes a fraction of the next most economical alternative; and final effluent quality -- where there is a final surface discharge -- is often far superior to that from other forms of more confined treatment.

I feel that the water, nutrients, and natural soil-builders in wastewater and sludge are too valuable to throw away and that land reclamation and crop production offer an ideal way to use them. We should continue to study more fully and to guard against problems caused by pathogenic organics and heavy metals by initially placing developmental emphasis on systems with built-in safeguards. But we cannot afford the "do-nothing" position that development of land application systems must wait until we fully understand all possible ramifications. We will never have full knowledge. The protection of our environment requires that we make maximum use of existing knowledge, whatever its shortcomings, as it becomes available and that we consider all reasonable alternatives before designing a waste treatment system.

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Chapter 16

IRRIGATION IN THE HUMID SOUTHEASTERN COASTAL PLAINS

C.J. Phene

ABSTRACT

In the humid Southeastern Coastal Plains, efficient plant growth requires accurately controlled soil-water management to minimize plant water, nutrient and oxygen stresses, runoff, soil erosion and nutrient leaching. Design requirements are given for an efficient soil-water management system based on high-frequency irrigation concepts. With this system, nutrient solution can be applied through a plastic porous tube to supply adequate water and nutrients to a portion of the root zone automatically, irrespective of rainfall. Results from an experiment comparing high-frequency porous tube, sprinkler and furrow irrigation show that soil water was more efficiently controlled with porous tube irrigation, resulting in water savings of from 25 to 50 percent and a yield increase of 10 percent. The components of the high-frequency porous tube irrigation system are grouped topically: (1) water source, pumping and filtering system, (2) plant nutrient-chemical metering and injection system, (3) water distribution and delivery system, and (4) irrigation control system. The function and application of each component group are presented. Major system design parameters are prescribed for given climatic and edaphic conditions, and approximate initial and

amortized material cost information is provided. Amortized yearly cost of \$166.26 per 4047 m^2 (1 acre) can be offset by conservation of energy, water, fertilizer and implement traffic.

IRRIGATION IN THE HUMID SOUTHEASTERN COASTAL PLAINS 1/

INTRODUCTION

C.J. Phene 2/

The Coastal Plains of the Southeastern United States extend from Virginia into eastern Texas and are bordered on the southeast by the Atlantic and Gulf Flatwoods, on the northwest by the Piedmont, and on the north by the Southern Appalachians and Ozarks (figure 1) (8). Within this region there are different geographic, climatic, topographic, and edaphic conditions where a variety of crops, cropping systems, and land and water occurs.

The Coastal Plains of North and South Carolina and Georgia (figure 1) encompass approximately 1.945×10^7 ha of land, which can be distinguished by similar crops, soils, topography, climate and land uses and high agricultural production potential. This area is characterized by flat to gently rolling topography, soils with a shallow A1 horizon underlain with a compacted horizon, low water storage capacity, low fertility, and high soil strength at low water content. Although mean annual rainfall exceeds 100 cm per year, much of this rainfall may not be utilized by crops, because the

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1/ Contribution from the Coastal Plains Soil and Water Conservation Research Center, Southern Region, Agricultural Research Service, USDA, Florence, S. C., 29501, in cooperation with South Carolina Agricultural Experiment Station.

2/ Soil Scientist

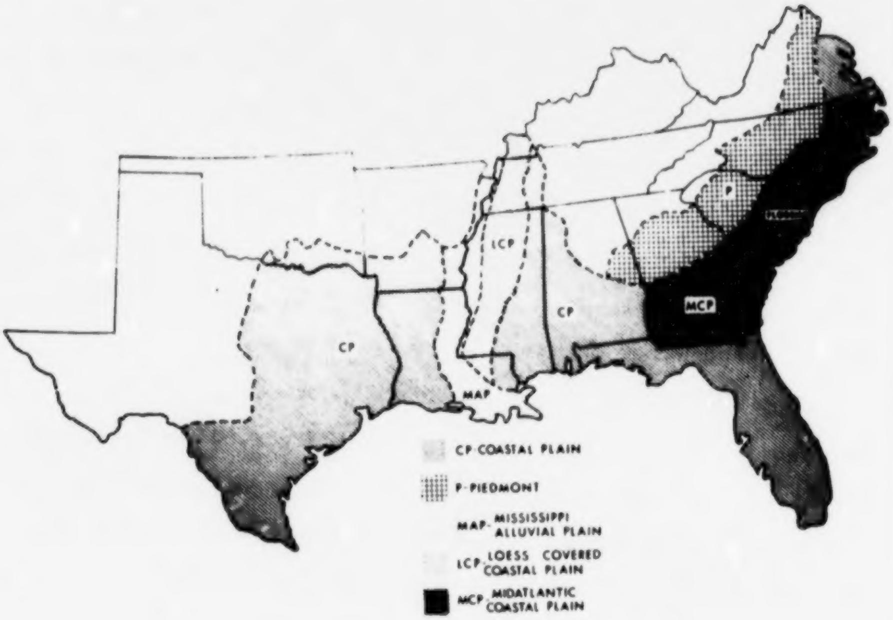
LCP
CP
CP
P
MCP
MAP
CP-COASTAL PLAIN
P-PIEDMONT
MAP-MISSISSIPPI ALLUVIAL PLAIN
LCP-LOESS COVERED COASTAL PLAIN
MCP-MIDATLANTIC COASTAL PLAIN

Figure 1. The Coastal Plains of the Southeastern United States.

erratic distribution during the growing season does not always coincide with crop requirements (16). Figures 2, 3, and 4 show the annual rainfall distribution, the monthly rainfall distribution and the growing season rainfall distribution, respectively, from 1926 to 1963 for the vicinity of Florence, S. C. Figure 2 shows a mean annual rainfall of 110 cm with a maximum of 190 in 1928 and a minimum of 70 cm in 1953. Figure 3 shows the variability of the monthly rainfall distribution, in particular, during the growing season when the monthly rainfall, averaged from 1926 to 1963, ranges from less than 5 cm to 35 cm in July. Figure 4 shows the variability of the growing season rainfall, between April and September, averaged from 1926 to 1964. This six-month period averaged 57 cm of rainfall with a low of 25 cm in 1954 and a high of 93 cm in 1928. These data demonstrate that rainfall in this area is highly unpredictable.

Most crops, growing in shallow sandy loam soils in this region, are detrimentally affected by intermittent water and oxygen stresses. These stresses affect various crops differently, depending on the growth stage of the crop and the magnitude of the stress, but some physiological damage that may decrease crop yields occurs (6, 11, 16). A typical growth pattern of a nonirrigated corn plant in a shallow-layered soil of this area is shown in figure 5. Plant roots are usually confined to the A1 layer, and, since water movement through

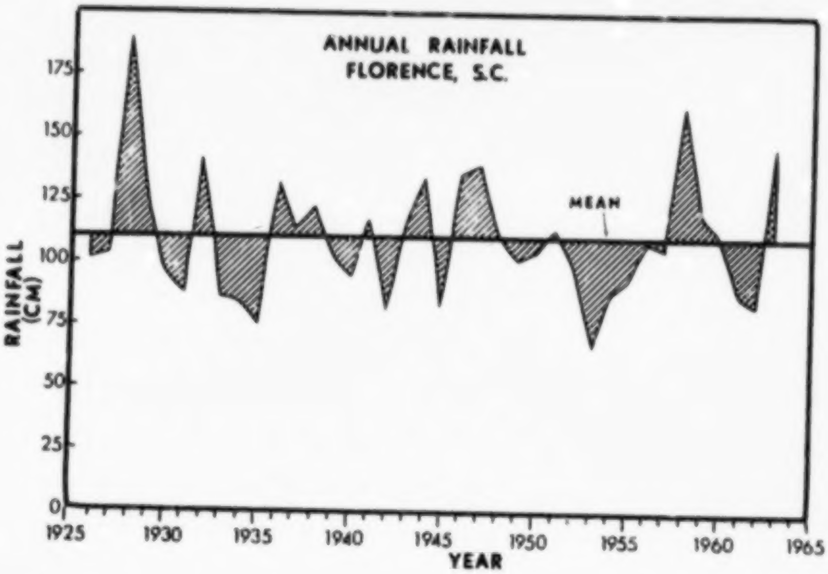

Figure 2. Annual rainfall distribution for Florence, S. C., from 1926 to 1963.

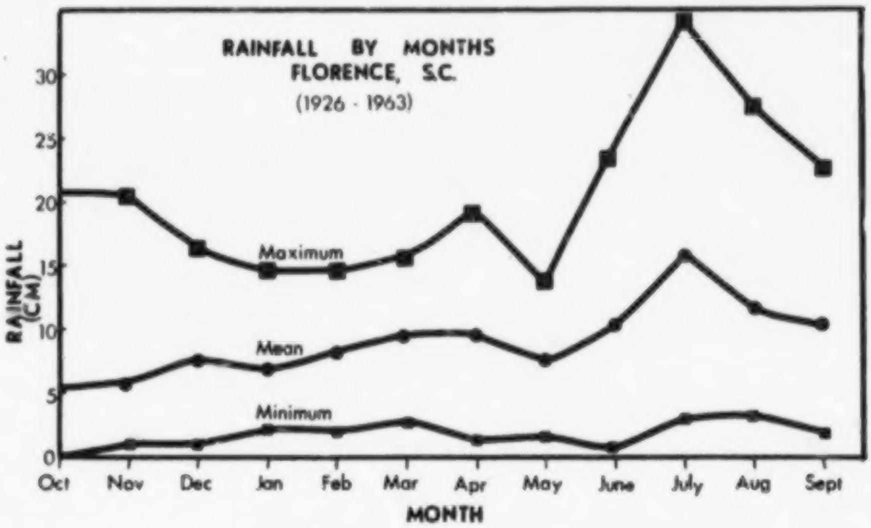

Figure 3. The monthly rainfall distribution for Florence, S. C., from 1926 to 1963.

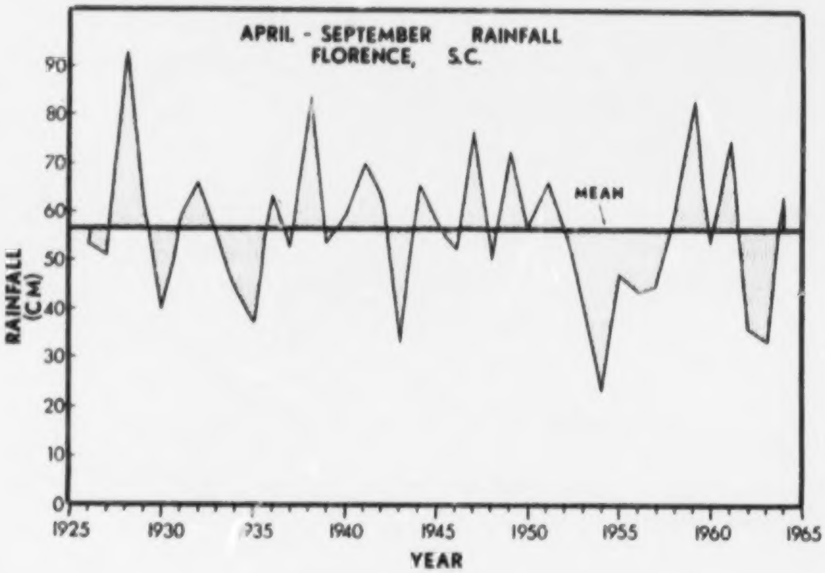

Figure 4. The April-September rainfall distribution for Florence, S. C., from 1926 to 1964.

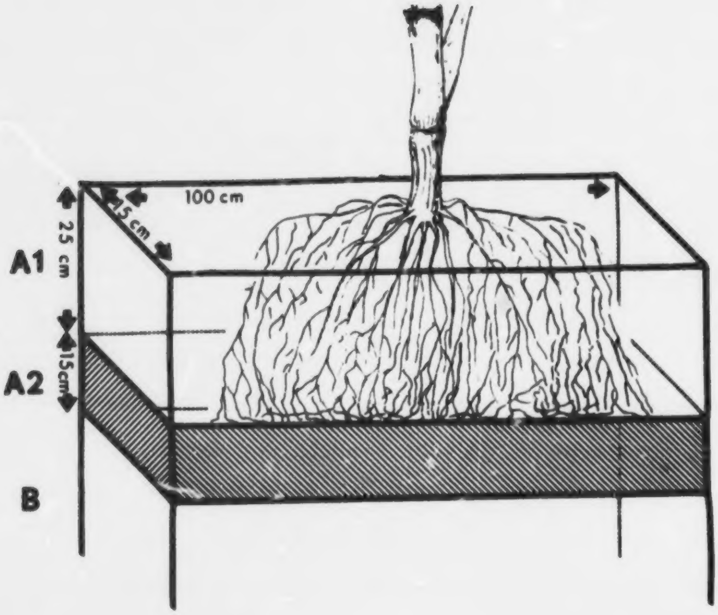
100 cm
15 cm
25 cm
15cm
A1
A2
B

Figure 5. Typical nonirrigated corn plant root system in shallow layered sandy loam soil of the Coastal Plains.

the soil profile is reduced by the underlying layers (9), water readily available to the plant is virtually contained in the A1 layer. In 5 to 10 days without rainfall and with evapotranspiration of 0.6 cm/day temporary drought will occur (6). Conversely, 3 to 6 cm of rain following an irrigation can saturate the surface soil with water, produce excessive runoff, and decrease the oxygen diffusion rate (ODR) to below the critical 4×10^{-8} ug/cm^2/min (18).

Figure 6 shows the soil water desorption curve, the unsaturated hydraulic conductivity (K), the soil matric potential limiting the ODR and the soil strength limiting root penetration for the A1 layer of a Varina sandy loam soil (2, 14). The narrow range of adequate soil matric potential for optimal plant growth implies that water excesses and shortages can occur successively within a few days. Irrigation, to prevent this type of drought, should not exceed the soil storage capacity and should be applied slowly to avoid waterlogging (6).

Irrigation of crops before the photosynthetic rate is decreased by water stress is economically advantageous. However, at the early stage of water stress, the probability of rainfall usually precludes irrigation with any high application rate surface irrigation systems, since a subsequent rainfall could saturate the soil and decrease ODR. When rainfall is nearly

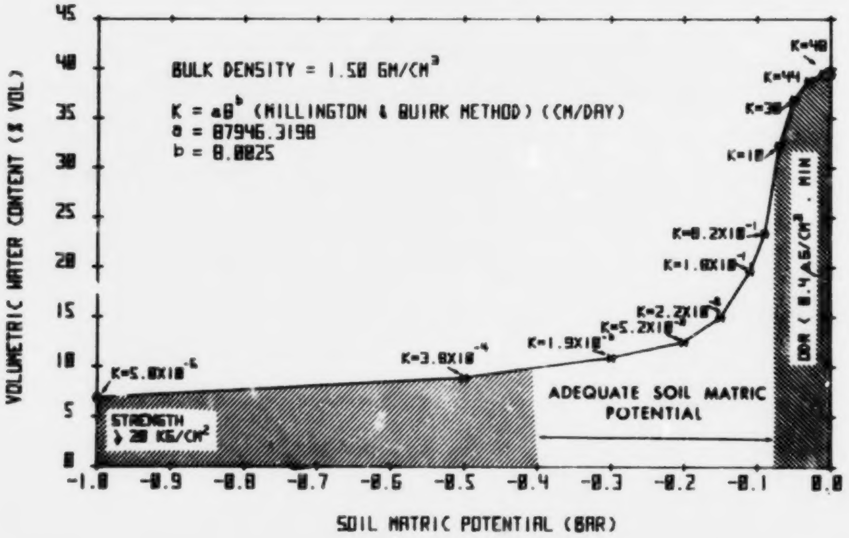

Figure 6. Soil water desorption, unsaturated hydraulic conductivity, and the growth-limiting ODR and strength-limiting soil matric potentials for the Al layer of a Varina sandy loam soil.

adequate, supplemental irrigation of forage crops may decrease yields, if crops are irrigated with systems requiring application of large quantities of water (7). Florence, S. C., where the experiments were conducted, is in the approximate center of the Coastal Plains of Georgia, South Carolina and North Carolina, and data reported are applicable to this area and probably to adjoining States.

Water Management Requirements

Water management in this area must encompass crop system parameters, such as soil, water, ODR and nutrients; farming practices and machinery use; availability of water and energy for irrigation; and soil conservation practices to minimize runoff, soil erosion and nutrient leaching. Irrigation needs in shallow sandy soils are not determined by the magnitude of monthly rainfall but rather by its distribution during the growing season. Often, water requirements in humid regions are given a low order of priority, unless soil-water management does not interfere with other farming practices and can be carried out simultaneously. An operative and efficient soil-water management system could be modeled with the following requirements:

1. Deliver water and nutrients slowly, in small quantities, and as frequently as required to maintain the soil matric potential and the nutrient supply in the desirable range to minimize runoff, soil erosion, nutrient leaching and ODR depression.

2. Apply water when needed irrespective of rainfall and/or prediction of rainfall.
3. Maximize efficiency under strict water and energy allocations and maintain trafficability for farm equipment.
4. Easily adaptable to irregularly shaped fields.
5. Capable of automation.
6. Economically feasible.

The order of priority of these requirements will be determined by individual conditions, farming objectives, crops, location, machinery availability, economics and, possibly, other inherent factors. Until recently, these inflexible, basic essentials may have impeded the successful development of irrigation in the Coastal Plains, because the available irrigation systems could not meet the requirements imposed. The technological advances of subsurface and trickle irrigation during the last decade permit economic installation of these systems in humid regions. In the Southeast, the abundant total rainfall suggests the feasibility of trickle and subsurface irrigation with brackish water since salinity buildup in the sandy soils is essentially obviated by the considerable yearly net downward movement of water (1).

Davis and Nelson (5) define subsurface irrigation as the application of water under the soil surface so that it moves by capillarity into the root zone of the crop. Through the subsurface irrigation system, adequate water can be applied slowly and frequently, with or without chemicals, directly to a portion of the root zone at low pressure. Usually, the application rate should be less than the infiltration rate to avoid water saturation, which might cause runoff and ODR depression. The frequent irrigations can be controlled to maintain adequate soil water and plant nutrients in a portion of the root zone in sufficient quantities to compensate for evapotranspiration and possible leaching losses when rain occurs. This eliminates extreme fluctuations of the soil matric potential, which are detrimental to crop quality and yield.

Phene and Beale (15) designed a high-frequency porous tube irrigation system which is a compromise between trickle and subsurface irrigation. The system applies water through a plastic porous tube (Viaflo tube, E. I. DuPont De Nemours, Wilmington, Delaware)[3] buried near the soil surface. By definition, this system differs slightly from trickle and subsurface irrigation because it consists of a line source of water buried near the soil surface so that water flows more by gravity than by capillarity (figures 7 and 8).

Phene et al. (13) demonstrated the adaptability of high-frequency porous tube irrigation to automatic soil matric

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[3] Trade names are used for identification purposes only and do not imply preference for this item by the U. S. Department of Agriculture.

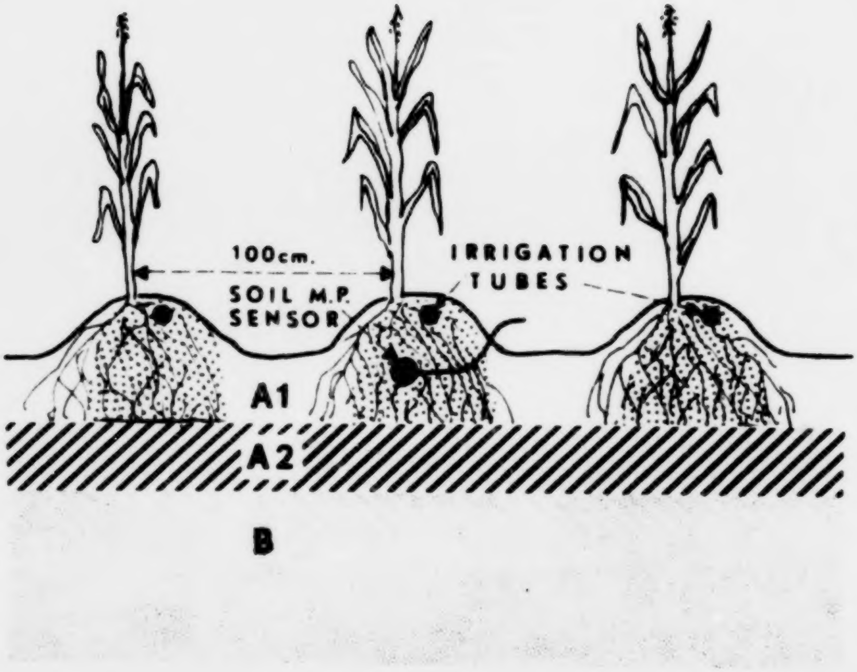
100cm.
IRRIGATION TUBES
SOIL M.P. SENSOR
A1
A2
B

Figure 7. High-frequency porous tube irrigation for conventional 100-cm row spacing.

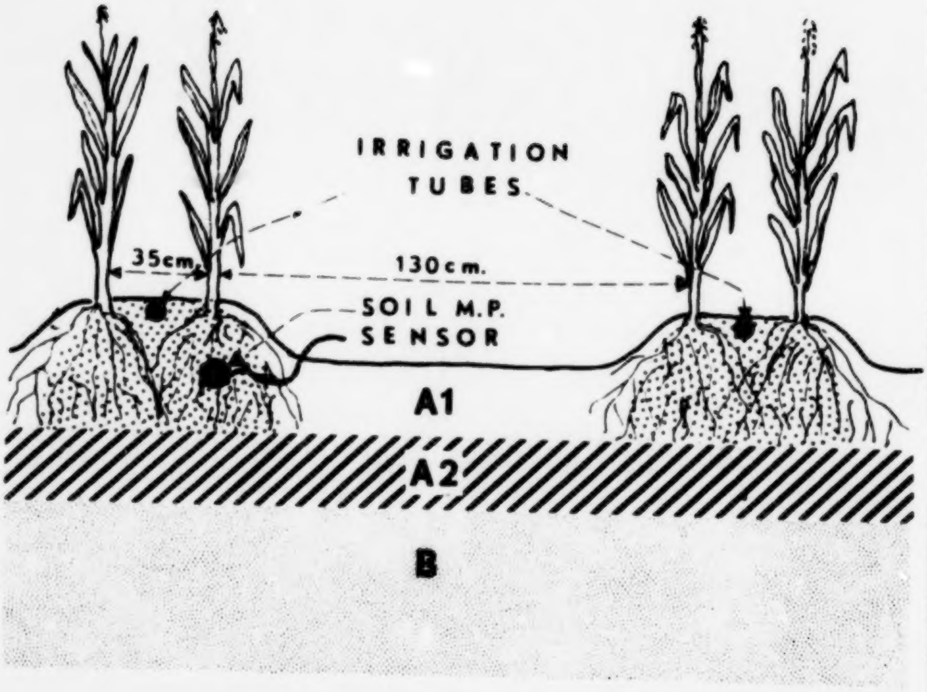
IRRIGATION TUBES
35cm.
130cm.
SOIL M.P. SENSOR
A1
A2
B

Figure 8. High-frequency porous tube irrigation for the "twin row" spacing.

potential sensor control. Results indicated that soil water in the restricted root zone could be accurately maintained within a narrow range of soil matric potential. Figures 9, 10 and 11 show the 15-cm depth soil matric potential fluctuations in experimental field plots planted to sweet corn. The individual plots were irrigated automatically for 15 minutes with plastic porous tube, sprinkler and furrow irrigation systems, respectively, when the soil matric potentials of each of the 3 treatments reached -0.100, -0.200 and -0.400 bar, respectively (15). Each arrow on figures 9, 10 and 11 indicates a 15-min irrigation. During this 5-day period, 30, 25 and 4 irrigations, totaling 10325 liters, were required to maintain the soil matric potential at -0.100, -0.200 and -0.400 bar, respectively, for all the porous tube plots. The sprinkler- and furrow-irrigated plots required 24, 16 and 5, and 14, 12 and 4 irrigations, totaling 13320 and 22920 liters, respectively, to maintain the soil matric potential above -0.100, -0.200 and -0.400 bar. The mean volumes of water applied were 175, 296 and 764 liters per irrigation, respectively, for the porous tube, sprinkler and furrow irrigation systems. Because water was applied often and near the plants with the porous tube, it was immediately available to the roots. By contrast, the sprinkler system applied water over the whole plot and only part of this water was available. The larger volume of water applied with furrow irrigation wetted the portion of soil with the fewest roots. Figure 12 shows rainfall, pan evaporation

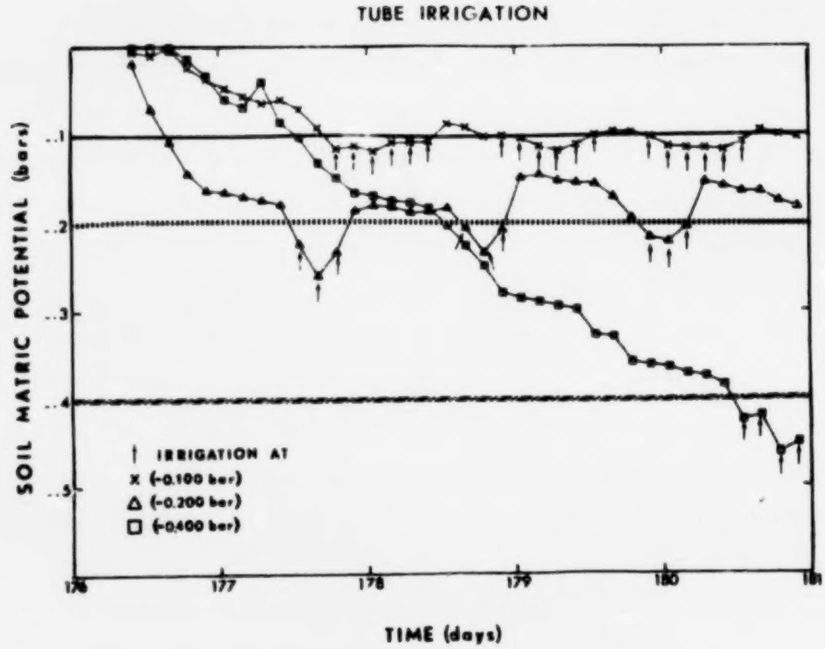

Figure 9. Soil matric potential fluctuations at 15-cm depth for high-frequency tube-irrigated plots controlled at -0.100, -0.200 and -0.400 bar.

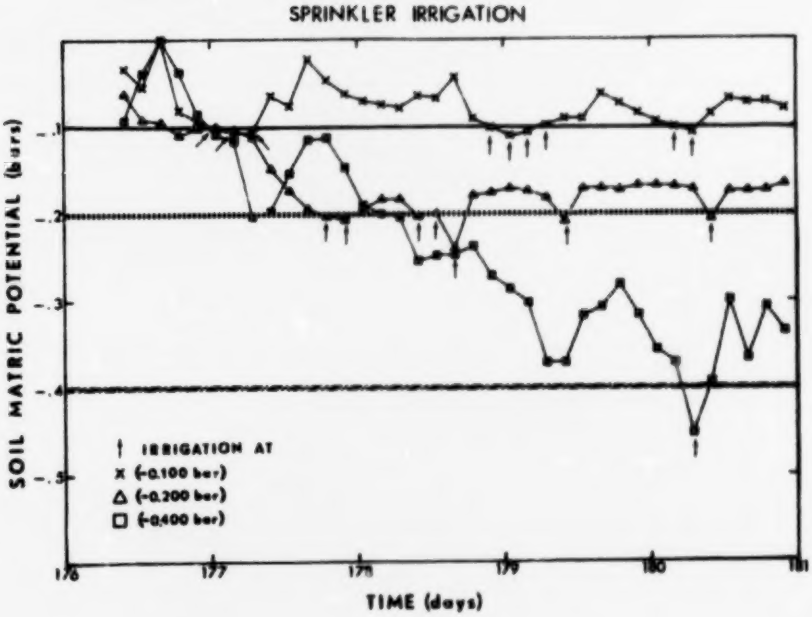

Figure 10. Soil matric potential fluctuations at 15-cm depth for sprinkler-irrigated plots controlled at -0.100, -0.200, and -0.400 bar.

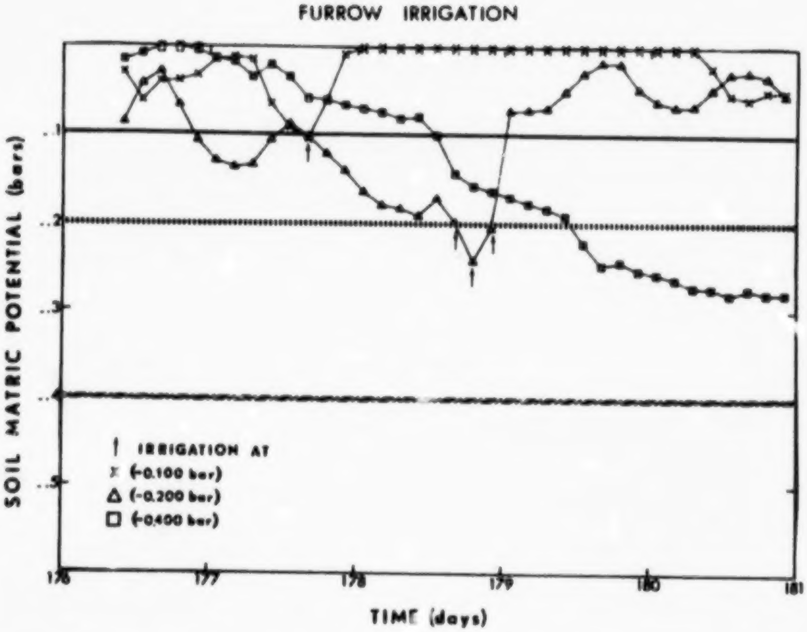

Figure 11. Soil matric potential fluctuation at 15-cm depth for furrow-irrigated plots controlled at -0.100, -0.200 and -0.400 bar.

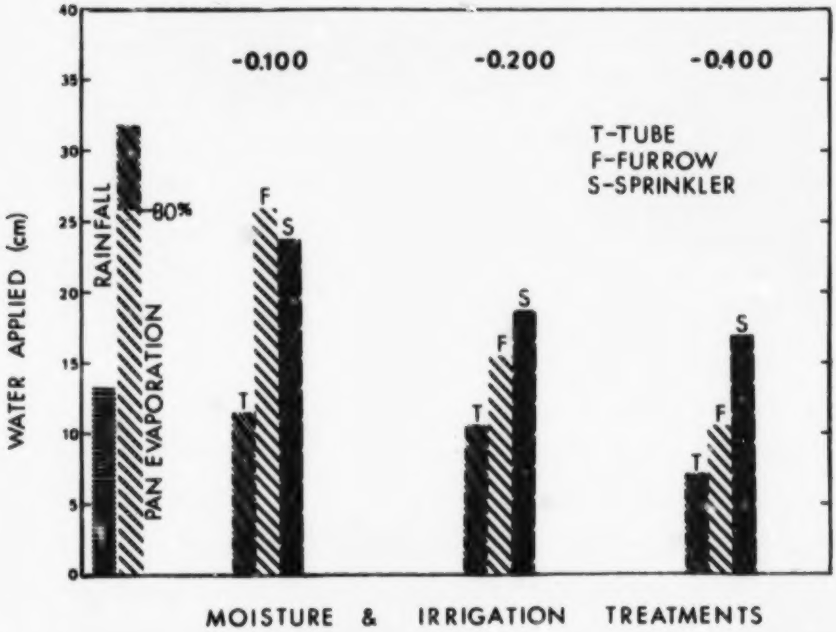

Figure 12. Water consumption for sweet corn irrigated by porous tube (T), furrow (F) and sprinkler (S) irrigation when the soil matric potential at 15 cm from the soil surface was -0.100 (M_1), -0.200 (M_2) and -0.400 bar (M_3).

and water applied for each irrigation treatment. Figure 13 shows the mean corn ear yield averaged for all the moisture treatments and the corn ear yield for each treatment. The differences between the porous tube irrigation treatment and the sprinkler and furrow irrigation treatments were significant at the 5 percent level. The soil physical properties, described in figure 6, and the yield of sweet corn obtained indicate that irrigation of this particular soil between soil matric potential values of -0.20 and -0.25 bar promotes optimum plant growth.

Frequent applications of small amounts of fertilizers and other chemicals conserve nutrients and minimize leaching losses due to overirrigation, runoff and rainfall. Distribution of fertilizers will be reasonably uniform along the row and their effectiveness will be increased by placing them near the roots.

Studies have demonstrated that the principal advantages of subsurface and porous-tube irrigation were the improved application efficiency and reduction of water use per unit area ranging from 25 to 75 percent of that required for sprinkler or furrow irrigation (3, 10, 14, 15). The high-frequency porous tube irrigation system can be designed to supply water at rates equal to maximum evapotranspiration and to apply water as often as required.

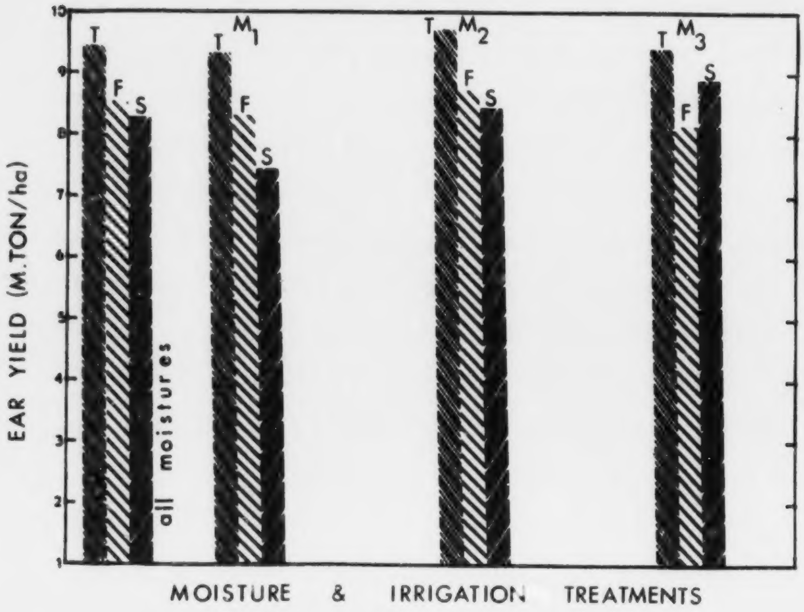

Figure 13. Yields of sweet corn irrigated by porous tube (T), furrow (F) and sprinkler (S) irrigation when the soil matric potential at 15 cm from the soil surface was -0.100 (M_1), -0.200 (M_2) and -0.400 bar (M_3).

Agricultural fields irrigated by high-frequency porous tube irrigation systems are not completely wetted. Usually, about 50 percent of the soil surface between rows remains dry, which will improve equipment trafficability during and after irrigation (4). If the soil matric potential in a portion of the root zone is maintained at -0.20 ± 0.05 bar, only a very small amount of water will be required for each irrigation and the probability of detrimental effects of subsequent intense rainfall will become smaller. Weeds will not grow as readily in this dry zone and runoff from excessive rainfall will be decreased. Considerable water may be stored in this dry zone (14). In a sprinkler- or furrow-irrigated field, this water might be lost to runoff or drainage.

The decrease in water requirement per unit area implies that a proportional percentage of energy required for pumping and delivering water will also be conserved. As water and energy supplies become more limited and allocations for agriculture come under economic pressure created by the high returns from industry and by recreation activities (12), high-frequency tube irrigation may contribute to a considerably higher agricultural production potential in the Coastal Plains.

Machine installation of the plastic tubing in various large scale field experiments has been described (4, 10, 20). The tubing can be installed at various soil depths by a tractor-drawn modified soil chisel. Multiple-row machinery may be easily adapted to install the tubing, simultaneously, during planting or transplanting operations.

Despite the advantages of irrigation, its present cost, especially for field crops, must be considered (4, 11). In addition to installation, other factors contributing to the maintenance and operational costs include adequate and dependable filtering of water, malfunctions caused by roots pinching the tubes, rodents and insects perforating the tube, or algae and chemical clogging of the tube. In some cases, these relatively high costs may be offset in the first year by conservation of water, energy and fertilizer and yield increase. Large energy saving will result mostly from a decrease in pumping cost and implement traffic.

The High-Frequency Porous Tube Irrigation System

High-frequency porous tube irrigation systems were designed for Viaflo tubing and have been used in field experiments to irrigate various row crops on Marlboro and Norfolk sandy loam soils at Florence, S. C. (13, 14, 15). Many design factors used for high-frequency porous tube irrigation systems are specific for each application and should be considered individually. The efficiency and economic feasibility of each system will be highly dependent on careful planning and design.

The components of high frequency tube irrigation systems can be grouped topically:

1. Water source, pumping and filtering system

2. Plant nutrient and chemical metering and injection system
3. Water distribution and delivery system
4. Irrigation control system

Water Source, Pumping and Filtering System - Ground water is usually cleaner and, therefore, better suited for this type of irrigation. Surface water can be used, but will require careful filtering. The small flow rate of water required may permit the use of a shallow well. Gravity flow systems have been satisfactory and economical for line pressure varying between 0.2 and 0.4 kg/cm^2 (15). Sneed (17) has listed the water supply capacity required to irrigate North Carolina orchards with various tree densities. The water capacity required per unit area for the Viaflo porous tube system to replace water lost by evapotranspiration from row crops, at selected line pressure of 0.21 kg/cm^2 and a 100-cm row spacing, is shown in table 1.

One of the most critical factors in the successful operation of the high-frequency tube irrigation system is the filtering of the water. Since the average pore size of the Viaflo tubing is 4u (19), particulate matter with a diameter equal to or larger than 4u must be removed. Although many filtering methods have been described (17, 19), I used a swimming pool sand filter, with grade # 20 silica sand, in

Table 1. Viaflo high frequency irrigation system

	English System Units	CGS Units
Maximum daily evapotranspiration	0.4 in	1.0 cm
Equivalent volume	10,692 gal/acre	$1\text{x}10^8$ ml/ha
Row spacing	40 in	$1\text{x}10^2$ cm
Length of Viaflo tubing required per unit area	13,068 ft	$1\text{x}10^6$ cm/ha
Manifold pressure	3 psi	210 g/cm^2
Viaflo tubing flow rate at above pressure	0.81 gal/ft/day	$6.9\text{x}10^{-2}$ ml/cm/min
Maximum pump capacity for above system	7.5 gal/min/acre	$7.014\text{x}10^4$ ml/min/ha

series with Cuno P-10 cartridge filters [3], which adequately filtered irrigation water for 2 consecutive crops of sweet corn grown during a 6-month period (fig. 14). Pressure gauges installed in the water line before and after the filters indicated a pressure drop on the discharge side, as the filter became clogged with suspended particulate matter. The filter cartridges were back-flushed periodically or replaced to restore an adequate water flow rate through the system.

Plant Nutrient and Chemical Metering and Injecting System - Plant nutrients such as nitrogen and potassium (13, 15), and water miscible pesticide emulsions such as chlordane and diazinon, can be easily applied with the high-frequency porous tube irrigation system by various methods (19). A chemical metering pump and mixing tank were used for quantitative applications of chemicals (15). The solution was mixed thoroughly, pumped through a filter and injected into the irrigation water line. Figure 14 is a schematic of the main distribution manifold including the filter, the fertilizer tank, pump and filter, the pressure regulators and valves and the sensor control system. Frequent checks of the chemical pumping system indicated that the initial calibration for application rate remained constant during the experimental period.

Water Distribution and Delivery System - Polyethylene (PE) or polyvinyl chloride (PVC) plastic pipes were used for

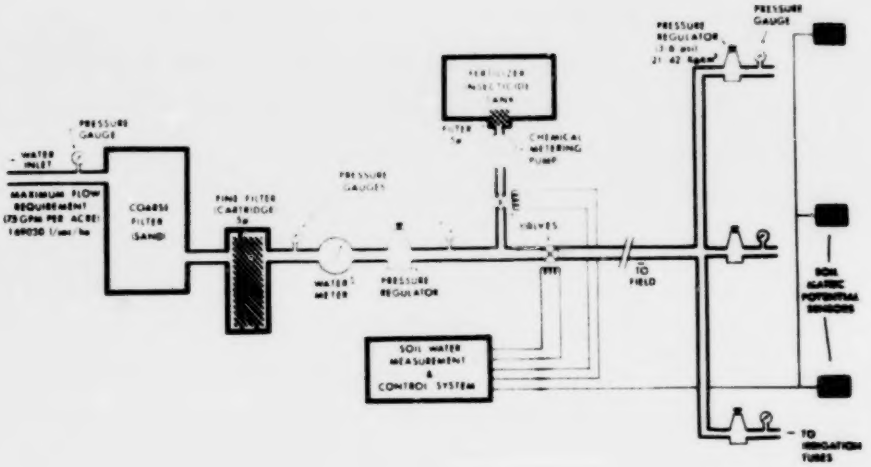
PRESSURE REGULATOR (3-6 psi 21-42 kpa)
PRESSURE GAUGE
FERTILIZER INSECTICIDE TANK
PRESSURE GAUGE
WATER INLET
FILTER 5µ
CHEMICAL METERING PUMP
PRESSURE GAUGES
MAXIMUM FLOW REQUIREMENT (75 GPM PER ACRE) 169030 l/sec/ha
COARSE FILTER (SAND)
FINE FILTER (CARTRIDGE 5µ
VALVES
WATER METER
PRESSURE REGULATOR
TO FIELD
SOIL MATRIC POTENTIAL SENSORS
SOIL WATER MEASUREMENT & CONTROL SYSTEM
TO IRRIGATION TUBES

Figure 14. Schematic representation of the water treatment, nutrient and chemical application system and soil matric potential measurement and control systems.

the main water lines. Since corrosive chemicals may be injected into the line, the use of plastic pipes and valves are preferred. Sneed (17) has outlined the line criteria and has shown tables indicating the friction head loss as a function of flow rate and pipe diameter for PE and PVC pipes.

In a low-pressure, low-flow system, the mains and laterals should be large enough to avoid frictional head losses. This will eliminate the use of additional pressure regulators. Mains and laterals should be buried below the plow depth.

In the experiments conducted at Florence, a secondary manifold was buried at the head of each plot and fitted with tube adapters, 0.95 cm in diameter. Thick-wall rubber tubing of the same diameter was used to connect the shallow tubing to the buried manifold. Figure 7 is the cross-sectional schematic of the irrigation system showing the soil profile, location of the tubing, the controlling soil matric potential sensor, and the corn plant. Rows were spaced 100 cm apart and the plant density varied from 60,000 to 75,000 plants/ha.

Figure 8 shows a similar cross-sectional schematic for a different row configuration referred to as the "twin-row" spacing. The twin-row spacing requires 33 percent less tubing length and the plant density is 25 percent greater than for the single-row. The twin-row spacing is more convenient and practical to use when farm machinery operations are required, because more space is available for equipment wheels, soil compaction is less near the root zone, and the tubing does not interfere with farming equipment operations.

Irrigation Control System - Available means for controlling this high-frequency porous tube system can vary from a simple electric clock timer to a computerized sensor-feedback system (4, 13, 14, 17). In humid regions, a fully automated irrigation system, which accounts for soil water, evapotranspiration and plant water stress, as factors in making a decision to irrigate, would function well to adequately fulfill the water management requirements listed previously.

Phene et al. (13, 14, 15) have used soil matric potential sensors and soil matric potential-evapotranspiration measurements to control high-frequency porous tube irrigation systems. Water savings ranging from 25 to 50 percent over furrow- and sprinkler-irrigated treatments were measured with sweet corn, when soil matric potential sensors were used to control the irrigation system (fig. 12). The system was designed to supply enough water to replace evapotranspiration of 1 cm per day in 12 irrigations. Subsequent experiments have shown that water use efficiency could be further increased by using simultaneous measurements of soil matric potential and pan evaporation, the latter being used to adjust the duration of the irrigation cycle.

Design Considerations and Approximate Cost of the Irrigation System

Designing a high-frequency porous tube irrigation system requires knowledge of soil physical properties, size, shape and topography of the field; specific crop water requirements, row spacing and anticipated machine operations should also be considered. The source, quality, and availability of water will also be important economic factors in a feasibility determination. When the soil properties permit, the tubes should be buried below the plow depth to facilitate field preparation. However, shallow installation, as shown on figures 7 and 8, is preferable in layered sandy soils because the upward flux of water is impeded by these compacted layers. Figures 15 and 16 provide bases for such a system design. Figure 15 shows the tube flow rate as a function of pressure and the flow that will satisfy maximum evapotranspiration requirement. Water pressure in the tube as functions of distance from the manifold and of manifold pressure is shown in figure 16 for tube installation at the soil surface or at shallow depths. Operation at lower pressure will improve the water distribution along the row; however, a well-graded field will be required for low pressure operations, unless the tubes are installed on a contour.

Part 1 of table 2 provides a component initial and amortized cost estimate for a high-frequency porous tube

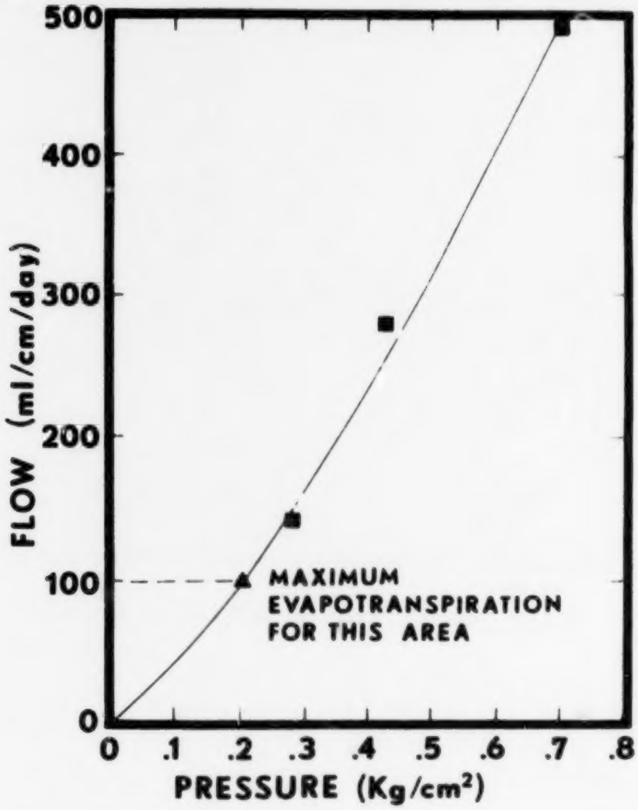

Figure 15. Flow rate through porous tubing as a function of water pressure for shallow soil installation.

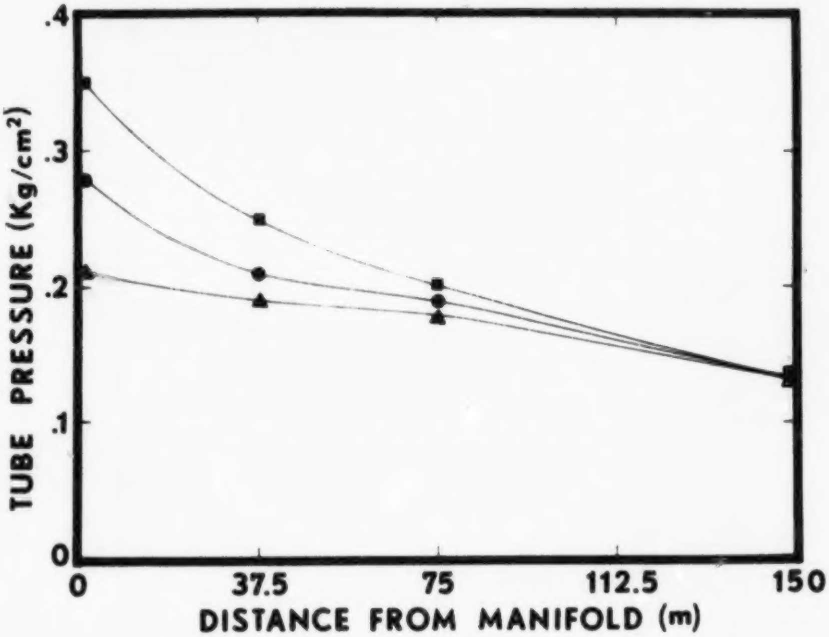

Figure 16. Pressure loss in porous tubing as functions of distance from the manifold and manifold pressure, indicated by zero-distance from manifold, for shallow soil installation.

Table 2. Approximate initial and amortized material cost per 4047 m^2 (1 acre) for a fully automated high frequency porous tube irrigation system (1973).

	Materials	Initial Cost $	Yearly Amortized Cost $
1.	Water pumping, filtering, distribution and delivery system. (1/2 HP shallow well pump) (amortized 10 years)	927.90	92.80
	Plant nutrient and chemical metering and injection system. (includes precision chemical metering pump) (amortized 10 years)	375.00	37.50
	Viaflo porous tube irrigation tubing. (amortized 3 years)	264.00	88.00
	Irrigation control system. (amortized 10 years)	500.00	50.00
	Miscellaneous yearly maintenance and replacement cost.		75.00
	Totals	2,066.90	343.30
2.	Approximate material cost per additional 4047 m^2 (1 acre) using the same system to irrigate up to 20,235 m^2 (5 acres).	600.00	122.00
3.	Approximate cost per 4047 m^2 (1 acre) based on a 20,235 m^2 (5 acres).	893.38	166.26

irrigation system designed to irrigate 4047 m^2 (1 acre) for a maximum evapotranspiration of 1 cm/day. This estimate includes some optional equipment which was used for research purposes and would not be required in a farming system. Part 2 provides the additional cost per 4047 m^2 (1 acre) when the capacity of the original system is increased to irrigate 20,235 m^2 (5 acres) and part 3 provides the cost per 4047 m^2 (1 acre) for a system originally designed to irrigate 20,235 m^2 (5 acres).

Summary

Water management requirements for layered sandy soils in the humid southeastern Coastal Plains were used to establish design criteria for an automatic water management system. The system is based on high frequency irrigation concepts and uses a plastic porous tube (Viaflo) to maintain adequate water and nutrient supplies in a portion of the root zone. Water and nutrients can be applied to the soil automatically when needed in small quantities and at low application rates irrespective of rainfall. Results obtained from an experiment comparing high frequency porous tube, sprinkler and furrow irrigation are presented. The components of the high frequency porous tube irrigation system are described and their functions explained. Major system design considerations are outlined and approximate initial and amortized cost information given.

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Chapter 17

CHEMICAL AND PHYSICAL PROPERTIES OF SOILS RELATED TO SOIL DRAINAGE

H.F. Perkins, M.C. Blount and J.S. Schepers

ABSTRACT

Soil drainage may be a cause or an effect of chemical, physical and biological properties of soils. Macro- and micro-relief influence movement of water through soils. Soil moisture regimes which range from saturation to air dry conditions largely determine higher categories of soil classification. Soil drainage affects the development of diagnostic horizons and features such as duripans, plinthite, fragipans, and spodic horizons which in turn cause perched water tables or otherwise retard movement of soil moisture. Degree of soil drainage influences soil color; state of oxidation of iron, manganese, nitrogen, sulfur and other elements; soil acidity; type and activity of microorganisms, production of certain toxic substances; and soil temperature.

Key Words: hydrologic sequence, land use, soil moisture regimes, diagnostic features, oxidation, reduction, specific heat.

Soil drainage influences the dynamic equilibrium in soils by controlling biological, chemical, and physical properties. Water, the universal solvent and essential constituent of all biological systems, moves through soils by saturated and unsaturated flow. It may enter the system by capillary rise from the water table or through

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percolation following precipitation.

Precipitation varies considerably from place to place (8), but the total volume is no guide to the actual amount entering the soil. This is determined by intensity of precipitation, vegetative cover, infiltration, permeability, and slope or relief. Although these factors influence the amount of water that may enter the soil, other factors, such as texture, structure, consistence, porosity, and chemical composition must be considered in evaluating interrelationships between soil drainage and chemical and physical properties.

SOIL MOISTURE AND SURFACE RELIEF

If soil parent material is uniform on a slope, it is possible to find a sequence of soil sites with progressively deteriorating drainage conditions downslope. This system is referred to as a hydrologic sequence (7). Excessively drained soils at the top of the slope are referred to as having normal drainage. Free-draining soils on side slopes contribute soil moisture to poorly drained soils on the lower slopes. A typical hydrologic system seldom exists, however. In reality, variation in geologic formations, soil parent materials, and other environmental conditions create a wide variety of drainage conditions for almost any given topography.

Movement of soil moisture within the soil may be in any direction, depending upon the center of force. Ballantyne (1) demonstrated this phenomenon when he observed that soluble chemical components of a soil may move upward or downward as well as laterally through the soil body. He found that drainage of the upper or topslope sites resulted in downward movement in the soil pedon. Lateral movement occurred on the sideslopes whereas upward movement existed on lower slope sites.

In general, we think in terms of three moisture regimes--saturation, moist, and dry. Soils may be found in either of the three moisture regimes, depending on their position in the landscape, since they may receive water from sources other than rainfall. Saturated soils may occur in arid climates as a result of run-off from mountains or the excess moisture may come from melting snow, seepage, or artesian waters. Soils in humid regions may be relatively dry if they occur on steep slopes or the soil is excessively sandy. In any given landscape that has uniform climate, adjacent soils may have different moisture regimes.

SOIL MOISTURE REGIMES AS RELATED TO SOIL CLASSIFICATION

The soil moisture regime refers to the presence or absence of water held at tensions less than 15 bars. Various soil moisture regimes (11) are defined on the basis of variations in water held at different tensions and on the groundwater level. The moisture regime is an important property of the soil in classification and land use since it influences many physical, chemical, and biological processes of soils. It is only a partial function of climate, although the amount and distribution of precipitation tend to determine many of the soil moisture regimes.

The aquic moisture regime implies poor drainage resulting in conditions favorable for chemical and biological reduction. Since there is little vertical movement of the soil water, it is generally stagnant. Under these conditions, dissolved oxygen must be almost entirely absent and the soil is saturated with groundwater or the capillary fringe for extended periods. If groundwater is always at or very close to the surface, the moisture regime is referred to as peraquic.

Soils have an udic moisture regime if, in most years, the soil moisture control section is not dry in any part for as long as 90 cumulative days. In general, the udic moisture regime requires a three-phase system (solid-liquid-gas) in at least a part of the soil. The udic moisture regime is common in soils of humid climates that have well distributed rainfall in which the amount of rainfall plus stored moisture equals or exceeds evapo-transpiration (Fig. 1). Percolation and leaching occur at some time in most years. If precipitation exceeds evapo-transpiration in all months of the year, this extremely wet moisture regime is called perudic.

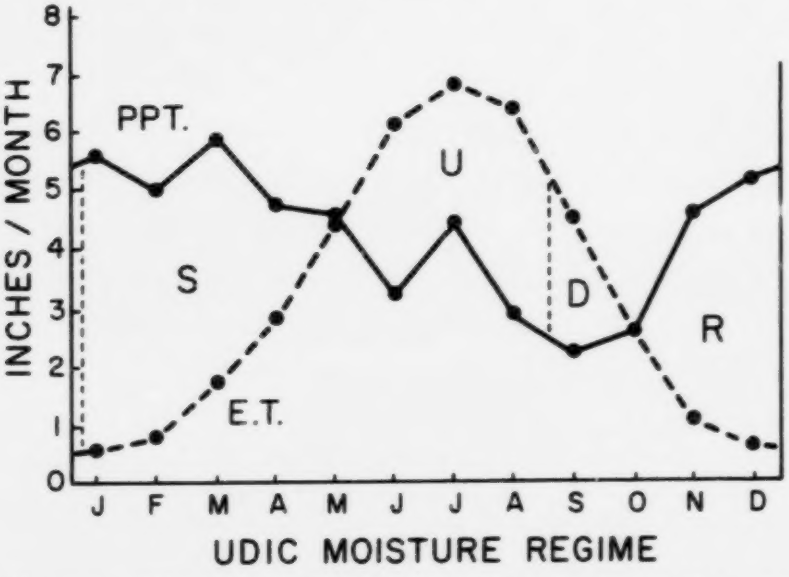

Figure 1. Climatic data for an udic moisture regime, Tallula, Louisiana (12). R = recharge, S = surplus, U = utilization, D = deficiency, PPT = precipitation, and E.T. = potential evapo-transpiration.

The ustic moisture regime is one of limited moisture but the moisture is present at a time when conditions are favorable for plant growth. In general, the moisture control section is dry for more than ninety cumulative days and moist for more than 180 cumulative days annually. The xeric moisture regime is typified by moist, cool winters and warm, dry summers. Rainfall comes during winter months when potential evapo-transpiration is at a minimum which creates conditions particularly favorable for leaching.

Aridic and torric moisture regimes are defined by the same parameters, except torric regimes must have hot, dry summers. Soils having either regime are dry in all horizons more than half the year (cumulative) and never moist more than 90 cumulative days. Soils under these moisture regimes normally have a high salt content, poor physical properties, and are not subject to leaching.

THE RELATIONSHIP BETWEEN SOIL MORPHOLOGICAL FEATURES AND DRAINAGE

Color is one of the most obvious and easily determined soil properties (10).It has little direct influence on the functions of the soil, yet one may frequently estimate the degree of natural soil drainage from this characteristic. The state of oxidation of iron compounds, which is related to soil drainage, largely determines soil color in soils with low organic matter content. Red colors in soils indicate good drainage and are usually due to oxidized and dehydrated iron oxides, although manganese dioxide and partially hydrated iron oxides may contribute to reddish colors in soils also.

Yellow colors of soils are generally dominant when iron oxides become hydrated. Hydration is prevalent in soils occurring in a moist climate; however, soils may still be considered well-drained. Frequently, organic matter content is present in sufficient quantity to subdue red or yellow colors resulting in soils with a brownish cast. Gray colors (moist chromas of less than 1.0 and values of 2.5 to 7.5 as determined by Munsell color standards) occur in soils that are permanently water saturated unless artificially drained. Under these conditions iron is in the ferrous form.

Severe soil drainage problems are seldom encountered with mature soil or soils that do not have genetic features which restrict drainage. However, texture, structure, clay mineralogy, organic matter, and man-induced effects may modify the degree of drainage. Each of the above features are interrelated. If soil structural aggregates are destroyed, free drainage of soils containing significant quantities of clay is restricted. Destruction of organic matter through cultivation results in similar effects. Erosion resulting from man's manipulation of the soil not only causes destruction of soil structure and reduction of organic matter content, but frequently results in an exposed subsurface horizon having high clay content. Soils containing clays with a high swell-shrink potential may create acute problems. Plowpans which restrict root as well as water movement are also features of poor soil management.

The presence of a perched water table, held above and detached from the main groundwater table by any horizon or stratum impervious to the passage of water is of considerable influence on the lateral movement of soil water. Since the zone restricting water movement is likely to be near the soil surface, it will confine movement within a thin veneer of the total soil body. Perched water tables have a geological or geomorphological origin. Any cemented or compacted horizon may function as a diagnostic soil feature and support a perched water table. Some of the more important features influencing water movement will be discussed in the following paragraphs.

GENETIC FEATURES INFLUENCING WATER MOVEMENT

One of the obvious features that restricts movement of water in the soil is the presence of bedrock or rock layers. When the soil makes continuous, coherent contact with underlying rock, it is referred to as lithic contact (4). Usually soils occurring under these conditions are excessively drained and droughty.

Another feature similar to lithic contact is a placic horizon. This horizon is a thin, dark red to black indurated and relatively impervious layer cemented with iron (11). It occurs in glaciated soils, whereas lithic contact may occur under any climatic condition. A petrocalcic horizon is a continuous cemented or indurated calcic horizon cemented by calcium carbonate or magnesium carbonate (11). It is a hard, massive continuous horizon. Although relatively impervious to water, it is of little consequence in the southern region of the United States, since it occurs in regions of restricted rainfall.

Plinthite is a subsurface feature that frequently causes perched water tables in Coastal Plain soils of the southern region. It is an iron-rich, humus-poor mixture of clay, quartz, sesquioxides, and other material, and occurs in soils as red mottles (4). Plinthite changes irreversibly to ironstone hardpans or septaria on repeated wetting and drying (6). Plant roots will not penetrate plinthite. A formation which may sometimes be associated with plinthite but more frequently exists under other environments are fragipans. A fragipan is a loamy or sandy, subsurface horizon that is low in organic matter and has a high bulk density (4). It is brittle but hard to very hard, slowly permeable to water, and resists root penetration. Fragipans may or may not be continuous; therefore, the degree of their influence varies.

The duripan is another genetically formed, impervious layer but it is cemented by silica (11). Duripans occur in certain soils which have a xeric moisture regime and in an environment where conditions are favorable for silica to become dissolved and leached into but not out of the soil. This formation exists along the coast of California and in other parts of the world having Mediterranean-type climate.

Spodic horizons are formed in many soils of the humid regions of the world, including the Coastal Flatwoods of the southern region of the United States. They have a marked influence on movement of water through soils. A spodic horizon is one in which active, amorphous materials composed of organic matter and aluminum, with or without iron, have precipitated (11). It is massive, quite hard, and has high water retention.

INFLUENCE OF POOR DRAINAGE ON BIOLOGICAL AND CHEMICAL ACTIVITIES

Poor drainage resulting in anaerobic conditions has a marked influence on some important biological and chemical properties of soils. Waterlogging frequently occurs in many areas in humid region soils which have high water tables or zones restricting drainage following heavy rainfall. The biological and physio-chemical changes that accompany waterlogging or submergence are important in determining land use suitability of the soil. Availability of some plant nutrients is lowered, whereas the production of toxic substances in soils is increased by the restriction in soil aeration. In well-drained soil, there is enough oxygen available from the atmosphere to supply the needs of microorganisms and higher plants. In the absence of oxygen, however, anaerobic microorganisms are active, which influence many oxidation-reduction systems in the soil that are important to the nutrition of plants.

Denitrification occurs under anaerobic conditions (9). Waterlogged soils may be so deficient in oxygen that some bacteria will reduce nitrates and utilize some of the oxygen from the nitrate ion for other purposes. In doing so, nitrate is reduced to nitrite or to ammonia, which may combine with a hydrogen ion and become ionized as ammonium hydroxide or become adsorbed to the cation exchange complex. Reduction of nitrate may be sufficient to release gaseous nitrogen as an oxide or in elemental form. Waterlogged soil conditions also promote reduction of sulfates to sulfides which may be toxic to plants.

Transformation of manganese from easily reducible form to the exchangeable form occurs under waterlogged conditions. Turner and Patrick (12) found an inverse relationship between easily reducible and exchangeable manganese during waterlogging. A similar relationship exists with iron where ferric iron is reduced to the ferrous form (9). Anaerobic conditions may increase soil acidity. As the soil pH is reduced, the availability of iron, manganese, and aluminum is increased. Frequently these elements are found in quantities that are toxic to the growth of plants (5).

Oxidation of organic matter is restricted, since the supply of oxygen from sugars, nitrates and/or sulfates is limited for use by anaerobic organisms. These organisms must obtain oxygen by reducing compounds such as carbohydrates or anions containing oxygen.

THE EFFECT OF DRAINAGE ON SOIL TEMPERATURE

Chemical and biological activities are an energy expression. Such changes, especially the latter, will not continue with adequate intensity unless certain temperatures are maintained. Therefore, the temperature of the soil is a factor of vital concern. For example, many biological systems do not begin activity until the soil temperature reaches 40°F and are most active between 80° and 90°F.

The amount of heat absorbed by soils is determined primarily by the quantity of effective solar radiation reaching the earth. Absorption is markedly influenced by soil color, slope, vegetation, and soil moisture or the interrelationships of these factors (3). Regardless of the angle of incidence of the sun's rays or the type of vegetative cover, dark colored soils absorb more energy than light colored soils. This fact does not imply that dark colored soils are always warmer than light colored soils. The amount of water which must also be warmed is quite important. Under field conditions, soil moisture content determines more than any other single factor the energy required to raise the temperature of soils. For example, the heat capacity of an average air dry sandy loam soil is approximately 0.26 calories per cubic centimeter as indicated in Fig. 2 (2). If moisture is added to approximately field capacity the heat capacity becomes 0.52 calories per cubic centimeter and at saturation the heat capacity increases to 0.78 calories per cubic centimeter. In other words, energy required to change temperature of a wet soil may be more than twice that for dry soil. Therefore, if a wet soil is drained, thus reducing energy necessary to raise temperature, the soil will warm up rapidly in the spring and become suitable for cultivation more readily. Inadequate drainage of soil during the spring may result in temperatures as much as 15°F cooler than those of well-drained soils.

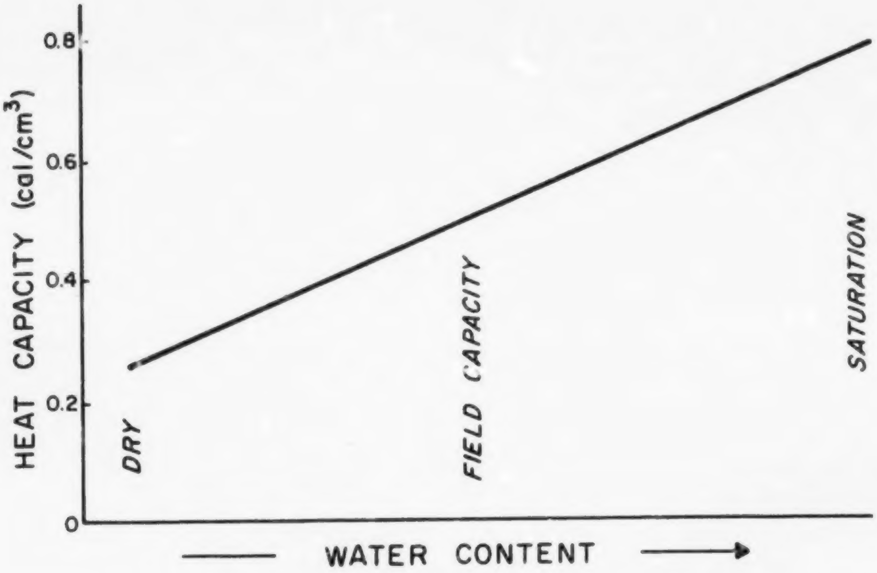

Figure 2. The heat capacity of a sandy loam soil as a function of soil moisture content (2).

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Chapter 18

SOIL DRAINAGE SYSTEMS AND FUTURE NEEDS

Robert E. Skinner

A drainage problem exists when there is an excess of water either on the surface of the soil or in the root zone beneath the surface of the soil. If water stands on the surface, the problem is one of surface drainage which can be remedied by one of several methods for removing surface water. The other type of drainage problem concerns water occurring beneath the surface of the soil. A high water table is present and frequently its presence is not evident from inspection of the soil surface. The soil surface may appear to be dry, and yet it may be waterlogged beneath the surface at depths which can cause serious damage to crops being grown.

Agricultural drainage may be defined simply as the removal and disposal of excess water from agricultural land. 1/ Drainage systems are needed to supplement natural drainage in many areas and have made possible agricultural development on much of the most productive land in the United States. The 1969 census of agriculture reports nearly 60 million acres

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Presented by Robert E. Skinner, Extension Engineer, Cooperative Extension Service, University of Georgia, Athens, Georgia at the Water Resources Symposium, Fort Valley State College, Fort Valley, Georgia, February 27, 1974.

of drained land in the United States on farms with sales of $2500 and over. 2/ The acreage reported as "drained land" refers to land which benefited to some extent by manmade drainage facilities such as ditches and underground drains. Georgia reported a total of 193,486 acres of drained land out of 3,410,595 total acres of harvested cropland on farms included in the 1969 census. The benefits to be derived from drainage are numerous. Some of the more apparent benefits are:

(1) Drained soils warm earlier in the spring, permitting early planting.

(2) A more uniform soil moisture occurs over the entire field and eliminates wet spots, permitting timely operation of tillage and harvesting equipment.

(3) Drainage increases the amount of oxygen in the soil and decreases the losses of nitrogen from the soil by denitrification.

(4) Soil structure is improved by drainage, permitting a deeper penetration of plant roots.

(5) Plants utilize lime and fertilizer more efficiently on well drained soils.

Agricultural drainage is divided into two broad categories: surface and sub-surface. Surface drainage includes measures to remove excess water from the land surface through improved natural channels, constructed ditches and land forming or grading. Generally classified as relief and interception drainage, subsurface drainage includes measures to remove excess water below the ground surface. Both ditches and buried drains are employed to collect and convey subsurface water.

Surface Drainage Systems

The objectives of surface drainage are to prevent water from ponding on land surfaces or in surface drains that must be crossed by farm equipment, and to remove excess water in time to prevent damage to crops. It must be an orderly removal of excess water in order to minimize erosion.

Surface drainage applies primarily on flat land where slow infiltration, low permeability, or restricting layers in the soil profile prevent the ready percolation of rainfall, runoff, seepage waters from uplands, and overflow from streams through the soil to deep stratum. The land surface to be drained should have a continuous fall to the field ditch, and the field ditch should have a continuous grade to the field lateral. 1/ The rate of water removal to be provided by the drainage system depends on interrelated factors such as rainfall characteristics, soil properties, and cropping patterns. For most row crops, surface drainage systems should complete removal of excess water from the soil surface within 24 hours after rainfall ceases. An even more rapid removal may be necessary for high value truck crops. 3/ The rate of removal, called the drainage coefficient, is the rate of water removal per unit area used in drainage design. 1/

Types Of Surface Drainage Systems

The basic surface drainage systems are the parallel system, the random system, and the cross slope or diversion system. 1/ The type to be used will depend primarily on the requirements of the site and must do these things:

(1) Fit the farming system.

(2) Cause water to flow readily from land to ditch without harmful erosion or depositing silt.

(3) Have adequate capacity to carry the flow.

(4) Be designed for construction and maintenance with appropriate and locally available equipment.

Random Ditch System

This system is adapted to flat or gently sloping land where only scattered wet areas require drainage. Ditches are located so as to intercept as many depressions as feasible along a course through the lowest part of the field toward an available outlet. The course selected should provide the least interference with farming operations and a minimum of deep earth cuts. The ditches should be shallow and have side slopes flat enough for farm equipment to cross. Land smoothing, grading, or bedding will help assure complete surface water removal on less permeable soils.

Parallel Ditch System

This system is used on land where the topography is flat and regular and where a random system is impractical or inadequate. Field ditches are established in a paralled, but not necessarily equidistant, pattern. The direction of the land slope usually determines the direction of ditches; field ditches are generally perpendicular to the slope, and lateral ditches run in the direction of the slope. The location of diversions, cross slope ditches, and access roads for farming operations may also influence the ditch location.

Cross Slope Ditch System

This system consists of one or more diversions, terraces, or field ditches built across the slope. It is used to drain wet sloping land, to prevent the accumulation of water from higher land, and to prevent the concentration of water in shallow pockets within the field.

The use of diversions or field ditches depend on the steepness of the slope, the permeability of the soil, and the possibility of water flowing from higher land onto the field being drained. Field ditches are best on slopes under two percent. Diversions apply to steeper land. Spacing of the ditches will vary with land slope. Land grading or smoothing between the ditches will improve operation of the system.

Bedding

Bedding resembles a system of parallel field ditches with intervening lands shaped to a convex surface. The beds are made by plowing, blading, or otherwise elevating the surface of flat land into a series of broad, low ridges separated by shallow, parallel dead furrows or ditches. Under most conditions, bedding is not considered an acceptable drainage practice for row crops because rows adjacent to the dead furrows will not drain satisfactorily. 1/

Land Forming

Land forming generally refers to the changing of a land surface to insure the orderly movement of surface water. Land smoothing and land grading are two methods used to improve the effectiveness of the drainage system. 1/

Land Smoothing

Land smoothing eliminates minor differences in field elevations and shallow depressions by use of special equipment. It does not require a grid survey and does not appreciably change the general contour of the ground surface. Better drainage with fewer surface ditches may be obtained by this method, and more efficient operation of farming equipment is possible.

Land Grading

Land grading consists of shaping the land surface by cutting, filling, and smoothing to planned continuous surface grades. This practice may require moving considerable quantities of earth from one portion of the field to the other; it changes the topography of the field. 4/ Land smoothing and grading equipment such as the landplane or leveler can work efficiently to tolerances of one tenth foot or less. Rough grading can be done with farm tractors and scrapers or a landplane. It is better to take thin layers from a large area; in making cuts, removal of all the topsoil from an area should be avoided. If fills from rough grading exceed six inches, allowance for fill shrinkage should be made.

The length of land-smoothing equipment varies from 20 to 50 feet. Larger levelers may require crawler type tractors for power. Those with span lengths of 20 to 30 feet may be pulled with wheel type farm tractors.

The ground surface should be plowed or disked prior to smoothing and should be free of vegetation and trash. If the area is in sod, it should be plowed three to six months before smoothing operations or farmed in a cultivated crop one year before smoothing.

Where it is necessary to expose subsoil, additional soil treatment should be given to exposed areas. Exposed areas can usually be brought back to normal production in a short time unless the subsoil is very low in fertility. It is generally better to expose small areas of subsoil than to have numerous pockets that hold water after rains.

Subsurface Drainage

Subsurface drainage is classified as relief and interception drainage. Relief drainage is used to lower a high water table. Interception drainage is used to intercept, reduce the flow, and lower the flowline of water in the problem area. Both of these types of drainage may employ open ditches and/or buried drains.

Althoush open ditches are lower in initial cost than drains, they have these disadvantages: they require rights of way, they reduce the area of land available for cropping, and they require more frequent and costly maintenance then drains.

Buried Drains

Drains may be fabricated from clay, concrete, metal, plastic or other materials of suitable quality. If properly installed, they require little maintenance. Drains are usually preferred by landowners because they do not remove any land from cultivation and because maintenance is considerablly less than for ditches.

Plastic Drains

The use of corrugated plastic polyethylene tubing for subsurface drains has grown rapidly since its introduction in 1967. Installation of this type of tubing on a large scale began in about 1967. Since that time, its use has expanded so rapidly that it now accounts for a considerable percentage of all agricultural subsurface drainage being installed. The annual footage of this material installed in Georgia has increased from approximately one million feet in 1969 to over two million feet in 1973.

Advantages

Some of the advantages to be cited for this material are as follows:

(1) It is quite light, ranging in weight from 72 to 85 pounds for a 250 foot roll of four inch tubing. It is flexible and requires less labor during installation than concrete or clay drain tile.

(2) The long lengths of plastic tubing result in better alignment in unstable soils. Joint openings are eliminated.

(3) The light weight of plastic tubing makes it easier to distribute on soft, wet fields.

(4) The use of plastic tubing may result in lower total cost of drainage systems.

Disadvantages

Plastic tubing has the disadvantage of reduced strength at high temperatures. When strung out in a field on a hot day the tubing can reach temperatures of 120° to 140°F. For this reason, precautions must be taken to prevent the impact of sharp, heavy objects or excessive pull on the tubing during installation. The tubing regains strength when its temperature returns to that of the trench bottom.

It also has a reduced flexibility at low temperatures. Even though its strength increases at lower temperatures, if the tubing is rapidly uncoiled at low temperatures, it may be stressed excessively and crack.

Some stretch may occur during installation and this can cause some decrease in strength. The amount of stretch will depend on the temperature of the tubing at the time it is installed, the amount and duration of drag encountered as it feeds through installation equipment, and the stretch-resistance characteristics of the tubing being used.

Plastic tubing will also float in shallow depths of water; if it floats during installation, it is difficult to get the backfill material around and over the material without causing misalignment.

Sizes Available

Tubing commonly used in agricultural drainage is four inches in diameter or larger. It is furnished in coils of various lengths. The larger sizes are produced in short, straight sections. It is now available in eight, ten and twelve-inch diameters.

Strength Requirements

In contrast to clay and concrete tile, corrugated plastic tubing is a flexible material. Failures of the plastic material occur by deflection or collapse, rather than by cracking as with rigid materials. Plastic drain tubing gains most of its soil load-carrying capacity by support from the soil at the sides of the tubing. A load on top of the tubing causes the material to bulge outward, its effect is to give the flixible tubing more load-carrying ability. The strength of the tubing must be sufficient to withstand the soil load without excessive deflection, collapse on top, or failure of sidewalls.

Corrugations

Research indicates that a four-inch corrugated plastic drain can carry about 75 percent as much water as a well-aligned four-inch clay or concrete drain tile on the same grade. 5/ This reduction in capacity is not significant for most lateral lines since they seldom flow full. Water enters the plastic lines through small valleys located between corrugations. A four-inch plastic drain line and a four-inch tile line with a 1/8-inch gap between tiles both provide 1 1/2 square inches of opening per foot of drain.

Installation Techniques

Grooving - A specially shaped grove is required in the trench bottom for plastic drain tubing. The groove improves alignment of the tubing, provides a firm base, and provides lateral support for the tubing as it deflects outward against the soil alongside the tubing. The groove can be cut in the trench by some type of forming tool attached to the shoe of the trenching machine or by cutters attached to the trenching wheel.

Blinding and Backfilling

Proper blinding and backfilling of tubing are essential. Granular top soil for blinding around and four inches above the tubing permits free water movement into the tubing and provides side support from particles with sizes. Coarse sand to fine gravel may be used as blinding materials under some conditions; stones or other hard objects should be avoided next to the tubing since they apply point loads and cause the tubing to collapse.

Blinding holds the tubing in place during backfill to insure proper alignment and to protect the tubing from the impact on rocks or clods.

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Chapter 19

DRIP IRRIGATION–A NEW SYSTEM FOR ENERGY AND WATER CONSERVATION

Jerry L. Chesness

INTRODUCTION

The Agricultural Industry as well as all other facets of America's technological society can no longer depend on a cheap, abundant energy supply. With no new energy source as yet available to replace fossil fuels we must design systems with lower net energy requirements. Drip (or trickle) irrigation is such a system. It holds great promise for conserving not only energy, but water and nutrients as well.

Drip irrigation is a system for slowly applying water directly onto the soil surface. Water is allowed to dissipate under low pressure from an outlet device referred to variously as an "emitter," "trickler," or "dripper." Emitters dissipate the relatively low pipe pressure (5 to 15 psi) by means of a small nozzle or long flow path. This results in discharges in the range of 0.5 to 2.0 gallons per hour.

In contrast to sprinkler or furrow irrigation drip irrigation does not periodically wet the entire surface of a field. Instead moisture is placed at several points around the plant and is distributed by capillary and gravitational movement. The objective is to provide each plant with a continuous supply of soil moisture sufficient to meet its transpiration needs. Because the system supplies the water on a daily basis the plant soil moisture is kept at or near "field capacity" all the time.

Drip irrigation is not as recent an innovation as many people might think. It was developed shortly after World War II in the United Kingdom by Dr. Smycha Blass. Dr. Blass later moved to Israel and began an intensive investigation of this concept of irrigation in the arid regions of the Negev Desert. Research is presently being conducted by England, Italy, Denmark, Japan, Israel, Mexico, the United States and several other countries. In the United States research has, in the last three years, spread from the arid southwestern states (California, New Mexico, Arizona, etc.) to the humid southeastern states such as Florida and Georgia.

This research has and is involved in all aspects of the system, i.e., from system hydraulics to crop response. Certain reoccurring research results have emerged irrespective of type of crop or geographic location. Water savings of 25 to 50 percent for row crops and 50 to 75 percent for orchard crops have been obtained with equal or improved crop response when compared to furrow and sprinkler irrigation. These savings are realized through higher system application efficiencies and the development of a local (near emitters) "intensive" root system. The net result being one of water and energy (to obtain and apply the water) conservation.

The multi-use view point has led to fertilizer application with the system. Using several light local applications over the growing season instead of a single surface application growers report up to a 50 percent reduction in Nitrogen fertilizer requirements.

In summary, reports from various researchers indicate that drip irrigation has the following potential advantages: (1) increased yields, (2) accelerated growth, (3) water savings, (4) fertilizer savings, (5) reduced weed and insect control costs, and (6) savings in energy costs. The main disadvantages of drip irrigation systems are: (1) sensitivity to clogging, (2) salinity build up, and (3) poor soil moisture distribution.

The purpose of this report is to arrive at a quantitative estimate of the water and energy savings possible using a drip irrigation system. This will be done by presenting an abbreviated design example of a self-propelled volume gun sprinkling system and a drip irrigation system.

DESIGN EXAMPLE

The design example will compare the initial costs, annual operating costs, annual energy requirements, and annual water requirements for the irrigation of 77.6 acres of mature peach trees.

Preliminary Information.

The peach orchard will be located in the Coastal Plains region of Georgia. The soil, Faceville sandy loam, has a water holding capacity of 1.28 in./ft. and an infiltration rate of 0.7 in./hr. The level field (Figure 1) will measure 1320 ft. by 2560 ft. with the trees on a 20 ft. by 20 ft. spacing. The effective root depth of the trees will be taken as 2.0 ft. and the maximum water use rate as 0.18 in./day. Cultural practices will include clean strips under the trees (herbicide controlled) with sodded middles (Figure 3).

Water will be supplied from a well located at the center of the field.

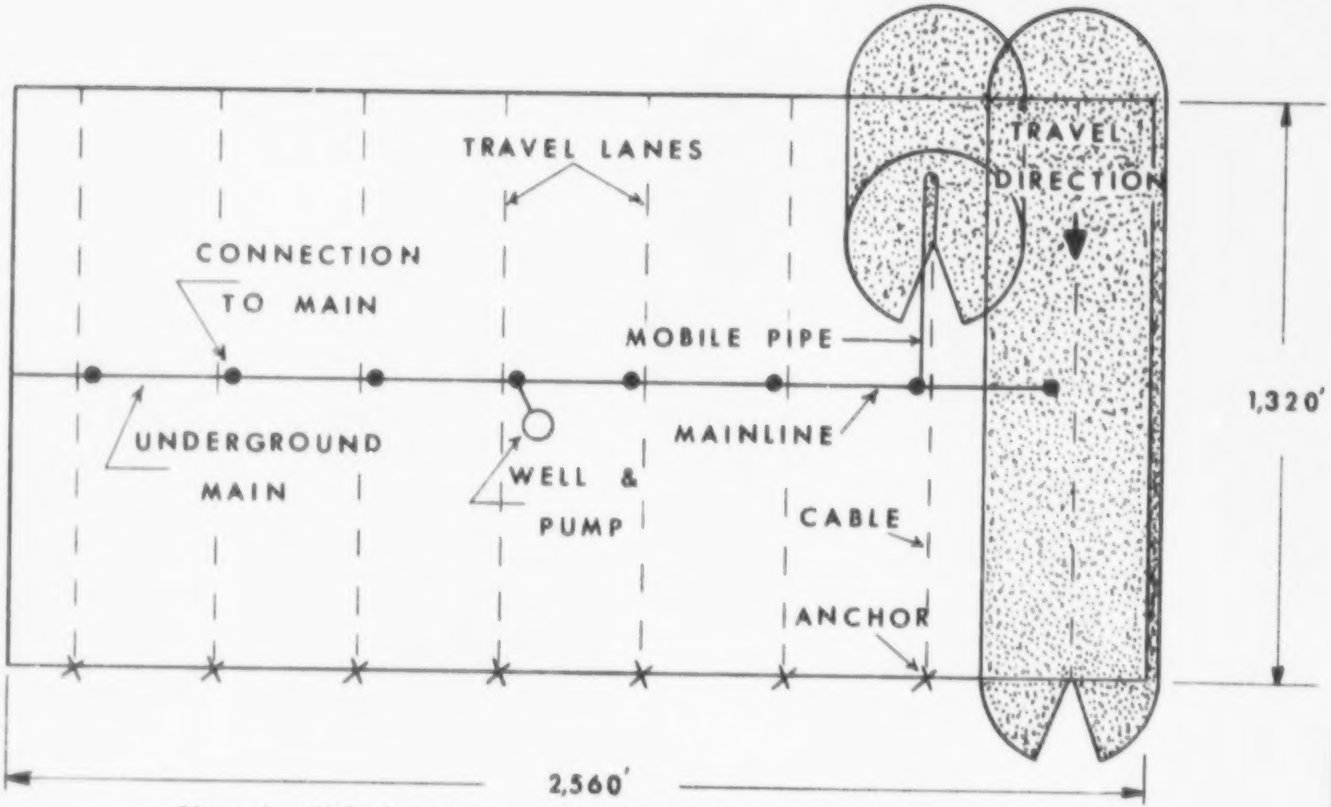
TRAVEL LANES
CONNECTION TO MAIN
UNDERGROUND MAIN
WELL & PUMP
MOBILE PIPE
MAINLINE
CABLE
ANCHOR
TRAVEL DIRECTION
1,320'
2,560'

Figure 1. Field layout for a self-propelled volume gun sprinkler system.

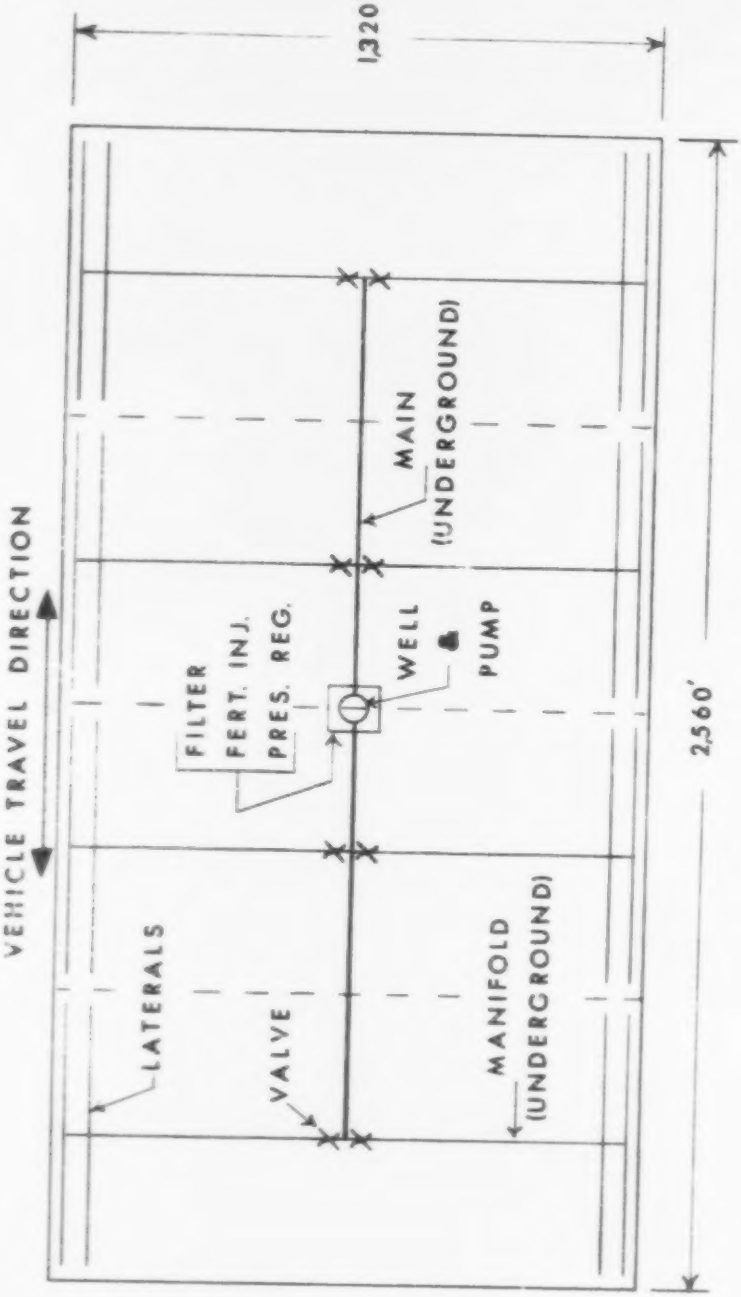
1320'
2,560'
VEHICLE TRAVEL DIRECTION
LATERALS
VALVE
FILTER
FERT. INJ.
PRES. REG.
WELL & PUMP
MAIN (UNDERGROUND)
MANIFOLD (UNDERGROUND)

Figure 3. Layout for the drip irrigation system.

Sprinkler System

1. Assume a 0 to 5 mph wind during operation with a lane spacing equal to 70 or 75% of the sprinkler wetted diameter.
2. Select a self-propelled volume gun delivering 550 gpm @ 80 psi over a wetted diameter of 440 feet.
3. Application Rate (in./hr.) =

$$\frac{96.3 \text{ x GPM}}{(.875) \text{ x Area of Wetted Circle (ft.}^2)} = \frac{96.3 \text{ x } 550}{(.875)(152,53)} = 0.40 \text{ in/hr}$$

4. Select a lane spacing of 320 ft. (see Figure 1) which is 73% of the wetted circle diameter. Each lane or pass of the volume gun will irrigate a strip 16 trees wide. Selecting the direction of travel (Figure 1) parallel to the short axis of the field will require eight lanes (128 rows) to completely irrigate the 77.6 acre peach orchard.
5. Allowing the available soil moisture to reach the 40% level before irrigating will require a gross water application (assuming a 70% application efficiency) =

$$\frac{\text{Holding Cap. (in/ft) x Root Depth (ft) x Available Moisture}}{\text{Application Efficiency}} =$$

$$\frac{(1.28)(2.0)(.6)}{.70} = 2.2 \text{ inches}$$

6. Irrigation Frequency = $\frac{\text{Net Water Replaced (in)}}{\text{Consumptive Use Rate(in/day)}} = \frac{1.5}{.18} = 8$ days
7. Sprinkler Travel Speed (ft./min.) =

$$\frac{1.605 \text{ x GPM}}{\text{Lane Spacing (ft) x Gross Water Appl. (in)}} = \frac{(1.605)(550)}{(320)(2.2)} = 1.25 \text{ ft/min}$$

8. Hours required to irrigate one ¼ mile long strip =

$$\frac{22}{\text{Travel speed (ft./min.)}} = \frac{22}{1.25} = 17.6 \text{ hours}$$

Therefore irrigate one 320 ft. by 1320 ft. lane every 24 hours allowing up to a maximum of 6.4 hours for moving and maintenance. The complete irrigation of the 77.6 acre orchard would require eight days.

9. Hp and pump requirements:

System Components	Head (ft.)
Nozzle operating pressure	197.3
Riser pipe	10.0
Propulsion turbine	8.0
Head loss in 660 ft. of 4 1/8 in flexible hose	69.0
Head loss in 1120 ft. of 6 in. PVC main line	22.4
Lift at well	60.0
Miscellaneous (fittings, valve, etc.)	10.3
Total =	377.0

$$\text{Hp} = \frac{Q(\text{gpm}) \times W(\text{lb/gal}) \times h(\text{ft})}{33{,}000 \times E_{\text{pump}}} = \frac{(550)(8.34)(377)}{(33{,}000)(.7)} = 75 \text{ hp}$$

Power requirements at the well will require a 75 Hp electric motor or a 100 BHp diesel.

Drip System

The drip irrigation system was designed for the level field layout shown in Figure 3 with the following design considerations:

1. Cultural Practices: Clean culture with herbicides under the trees (6 ft. wide strip) and sodded center strips (14 ft. wide) will be followed. Strips or traffic lanes will run in a direction parallel to the long axis of the field.
2. Design Application Rate: Peak water requirements have not been sufficiently well defined for drip irrigation to be used with confidence in lateral design. The design application rate can be estimated (Hiler - 1972) by reducing the peak consumptive use rate for sprinkler and surface irrigation by a crop coverage factor. The crop coverage factor is the fraction of the total tree space area (400 ft^2) covered by the tree. A tree canopy diameter of 14 ft. will be assumed resulting in a coverage factor of 0.39.

   $$\begin{aligned}\text{Design Application Rate} &= 0.623 \times \text{Peak Consumptive Use (in/day)} \\ &\quad \times \text{Tree Space Area } (ft^2) \times \text{Coverage Factor} \\ &= 0.623 \times .18 \times 400 \times .39 \\ &= 17.5 \text{ gal./day/tree}\end{aligned}$$

3. Emitter Arrangement: In a light textured soil (Faceville Sandy Loam) lateral moisture movement from the emitter should reach 3 ft. at the 10 inch depth. Selecting the emitter arrangement shown in Figure 2 will provide an irrigated root zone area equal to 21% of the gross area allocated to the tree. This percentage should be adequate for supplemental irrigation in the Southeast.

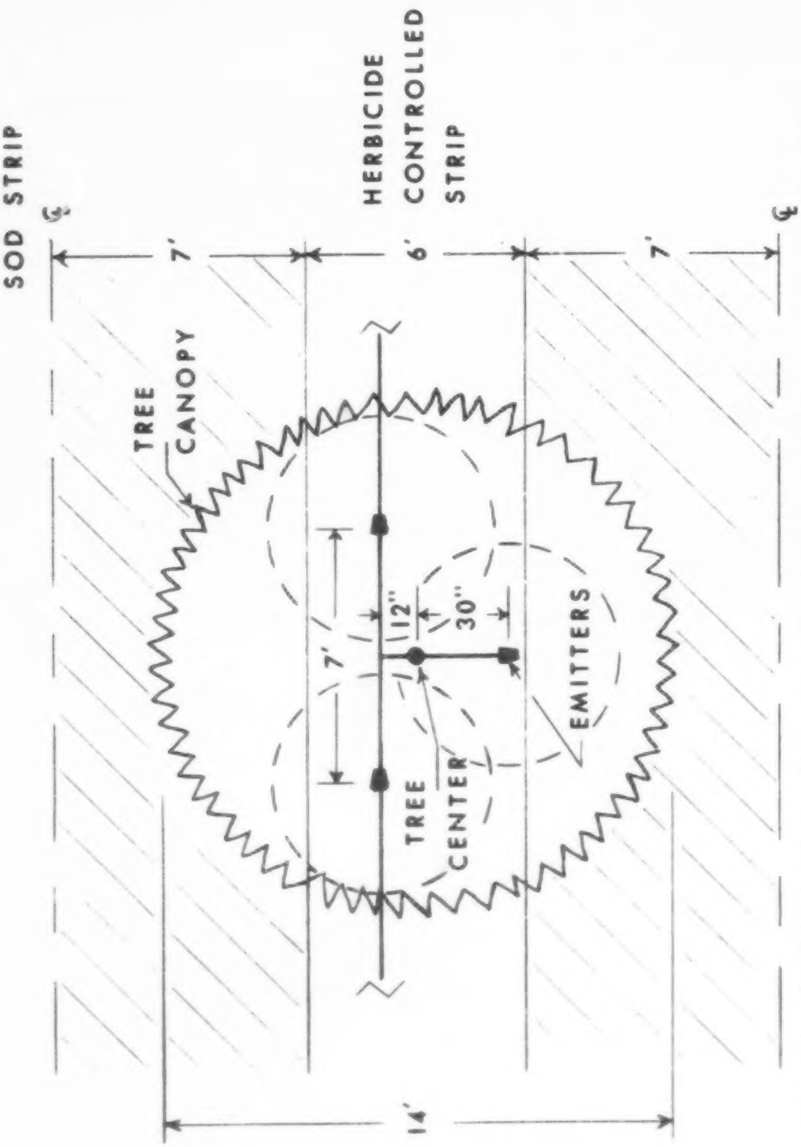
SOD STRIP
℄
7'
HERBICIDE CONTROLLED STRIP
6'
7'
℄
SOD STRIP
TREE CANOPY
7'
12"
30"
EMITTERS
TREE CENTER
14'

Figure 2. Drip irrigation emitter arrangement for each tree.

The arrangement also allows a single lateral to be employed reducing cost and traffic interference.

4. Emitter Flow Rate: The emitter flow rate can be calculated from the following equation:

$$\text{Discharge (gal./hr.)} = \frac{\text{Design Application Rate (gal/day/tree)}}{\text{Application time(hr/day)} \times \text{No. of Emitters per tree}}$$

$$= \frac{17.5}{(12)(3)} = 0.48 \text{ gal/hr.}$$

Adding 10% for evaporation and deep percolation losses brings the discharge rate to 0.53 gal/hr. A type B emitter (labyrinth flow path) operating at 16 psi will provide this discharge.

5. Lateral Size and Layout: Dividing the orchard into eight operational units as shown in Figure 3 will require 66-310 ft. long laterals per unit. Each lateral will supply 16 trees through 48 emitters.

Selecting ½ inch polyethylene pipe for the laterals results in a friction head loss of (Keller - 1973) less than 0.4 with a corresponding emitter emission uniformity of approximately 100%.

6. Manifold Size: The manifold in each of the eight operational units must supply water to 3,168 emitters with a total flow of 28 gpm. Selecting a 1.5 inch diameter polyethylene pipe for the manifold results in a friction head loss of 7.5 ft. for the 650 ft. length. Placing the manifold underground with a riser and tee connection to each lateral will allow vehicular movement over all sod strips.

7. Main Line Size: Each operational unit must operate 12 hrs./day to meet the tree's water use demands. Thus, four units must operate simultaneously with a total flow requirement of 112 gpm. Selecting a two inch diameter polyethylene pipe the total friction head loss for each 960 ft. main is 19.2 ft. The main will be placed underground to increase life and field mobility.

8. Pump Size and Hp Requirements:

	Head (ft.)
Emitter discharge pressure	36.9
Lateral head loss	0.4
Manifold head loss	7.5
Main line head loss	19.2
Filter, fittings, etc.	26.0
Lift at well	60.0
Total Head =	150.0 ft.

$$\text{Hp} = \frac{\text{Discharge (gpm)} \times \text{Density of Water (lb/gal.)} \times \text{Total Head(ft)}}{33{,}000 \times \text{Pump Efficiency}}$$

$$= \frac{112 \times 8.34 \times 150}{33{,}000 \times .70} = 6.1 \text{ hp}$$

The Hp requirements at the well can be meet by a 7.5 Hp electric motor. During moisture defficient periods the system will operate continuously. During each 12 hr. period four units will be "on" irrigating one-half the total orchard area.

System Comparisons

The cost,* energy and water requirements for the drip system,

*Local prices in effect on February 18, 1974.

sprinkler system (electric) and sprinkler system (diesel) are presented in Table 1.

Annual operating charges were based on an average annual operating period of 32 days (between March and October). This is the average number of days each year when soil moisture is considered defficient (van Bavel and John Careker - 1957).

The total fixed costs for each system includes the costs of a 300 ft. deep drilled well. Electric power costs do not include service line installation.

The fixed cost (initial cost of the system) for the drip and sprinkler (diesel) are very close. The initial cost savings for the electric powered sprinkler system could well be off-set by line installation costs and the increase in annual operating costs. It should be pointed out that these are not the annual fixed costs which would include ammortization of the initial cost over the expected life of the system components. The above ground portion of the drip system may well have a shorter life than that for the sprinkler system.

The major savings, dollar-wise, for the drip sys tem is in the annual operating costs; fully 1/4 of those for the sprinkler system.

In order to compare the average annual energy consumption between systems the electric generating losses at the power plant were accounted for. It is assumed that electric transmission losses are equal to fuel transport energy requirements. Taking this into account we see that the sprinkler system requires approximately eight times more energy (BTU's or gallons of diesel fuel equivalent) to operate than the drip system.

Table 1.

IRRIGATION SYSTEM COMPARISONS

CATEGORY	DRIP (Elect.)	SPRINKLE (Elect.)	SPRINKLE(Diesel)
Total Fixed Cost	$24,388	$18,507	$23,789
Annual Operating Cost			
Energy	$234	$1,956	$1,502
Other	$325	$ 282	$ 491
Total	$559	$2,238	$1,993
Annual Energy Use			
At the Pump	19.7×10^6 BTU's	144.2×10^6 BTU's	525.7×10^6 BTU's
At the Generating Plant	60.5×10^6 BTU's	443.4×10^6 BTU's	---
Fuel	432 gals.	3167 gals	3755 gals
Annual Water Requirements	11.6 ac-ft	57.0 ac-ft	57.0 ac-ft
Additional System Uses			
Annual N Applications Savings	$2,400	0	0

The sprinkler system also requires five times more water to operate. A factor which even in the humid southeast, can be significant.

Additional benefits could be gained by the drip irrigation system. Limited research has indicated a possible annual Nitrogen savings of 50%. Instead of one annual surface application several more efficiently applied liquid applications can be handled through the drip system. Assuming an annual application of 2.5 lbs. of N per tree this savings (at 160 $/ton for 34.5% Ammonium Nitrate) would amount to $2400 a year.

Conclusions

Additional research is needed to determine crop response to: (1) reduced water quantities, (2) reduced % of root zone wetted, (3) fertilizer applications, and (4) possible pesticide applications. When more of these questions are answered we will then know if the drip irrigation system "which looks good on paper" will live up to its projected potential.

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Chapter 20

WATER MANAGEMENT FOR VEGETABLES AND SOME SMALL FRUITS

Douglas C. Sanders and Sauveur Mahotiere

ABSTRACT

Vegetables are a very succulent food stuff and are composed of high concs of water (80-95%). Any reduction in this high conc of water can seriously affect the quality of edible portions. Many quality disorders associated with water balance are discussed. Blossom end rot of tomato and hollow heart of potato are some of the most common disorders resulting from water imbalance. Yields of most vegetables are greatly reduced by s of below 50% available. The critical stage for water supply for most of the vegetables is when they are producing the edible portion i.e. root, stem, seed or fruit. However, most vegetables require a uniform supply of soil moisture throughout the growing season.

The discussion of 'when to irrigate' has been greatly assisted recently by the use of several scheduling methods discussed. Of special note are the evaporation accounting system (Martin) and stress day index system (Hiler).

There are many ways of adjusting water deficit in vegetables. Antitransparants have been discussed and found somewhat limiting. The use of drip irrigation certainly has merit. The impermeable moisture barrier used in sandy soils has appreciable advantage. Evaporative cooling (EC) irrigation is of special use in vegetable crops since it can reduce stress on a plant and is a shunt of the soil uptake process. Evaporative cooling has been shown to be beneficial in many small fruits and vegetables. The use of water management in vegetables or fruits is just beginning to be understood and provide benefits in yield and quality.

WATER MANAGEMENT FOR VEGETABLES AND SOME SMALL FRUITS

By

Douglas C. Sanders[1]

and

Sauveur Mahotiere[2]

INTRODUCTION

Horticultural crops add much to the quality of life, as the old adage goes "man does not live by bread alone". So too man must savor new flavors and feast his eyes on new sights.

Vegetables and fruits add variety and vitality to our diets but as in no other crops water may be considered most important. Most vegetabler and fruits range from 80 to 95% water in their edible portion (Table 1). When vegetables or fruits lose their turgidity they lose their appeal; no one likes a 'limp' carrot, a 'floppy' bean or a 'shriveled' potato. So, in terms of weight, we buy a lot of water when we buy fresh vegetables and fruits.

Water is unique in the fact that all three physio-chemical phases are found in the temperature range of the normal environment. It plays a dominant role in crop production and plant processes. Water is intimately involved in all aspects of plant life from cell division to cell expansion. Water deficit in the plant results in marked impact on the

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Table 1. Water content of certain vegetables and small fruits. 1/

Species	Edible Part	Percent Water
Carrot	root	88.2
Potato	tuber	79.8
Asparagus	stem	88.3
Cabbage	leaf	86.0
Lettuce	leaf	94.8
Tomato	fruit	94.1
Strawberry	fruit	89.1
Sweet Corn	seed	84.8

1/ After compilations from various sources by Sanders.

photosynthetic processes, nutrient absorption and translocation, carbohydrate metabolism, nucleic acid and enzyme biosynthesis, just to name a few.

The need for correction of water deficit via irrigation seems questionable in a humid area with an average yearly precipitation greater than 40 inches, such as the Southeastern United States (80). However, at least in one out of ten years, water deficits exceed 5 inches in soils which hold only 3 inches of water in the root zone (Fig. 1). Many soils in this region do not even store that amount.

The rate and timing of irrigation should be dependent upon the crop, its stage of growth, plant density, soil water holding capacity and potential, precipitation patterns, and daily energy load on the plant.

In areas of high precipitation, correction of water deficit is not the unique concern because quite often there are also periods of excess

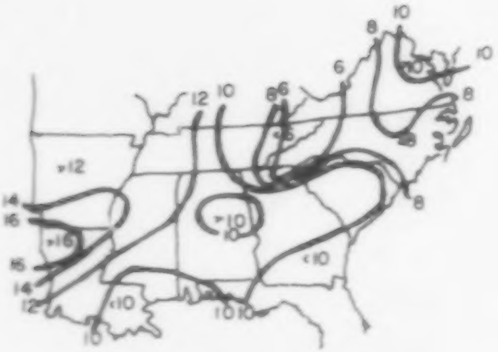

Fig. 1. An example of a simple but significant application of weather data to the study of water resources. The map shows the minimum water deficit (inches) to be expected in 1 out of 10 years, in growing crops on soils that can store 3 inches of water in the root zone. After Van Bavel (80)

water in the root zone (70). Thus surface and subsurface drainage are also of great importance in reducing plant water deficit due to soil saturation. Although considerable work has been done on drainage, relatively little has been done with vegetables. Little is known about the effect of high water table and soil saturation on the physiology of vegetables.

In this paper we hope to provide information about the impact and implications of water management for vegetables and small fruits.

CHANGES IN QUALITY AND INCIDENCE OF DISORDERS ARISING FROM WATER DEFICIT

Insufficient water causes not only reduced yields in vegetables and small fruits, but due to the succulent nature of the edible portions, water imbalance can cause special quality problems. Table 2 lists some of the deficits and disorders arising in major vegetables and small fruit crops which are related to water balance.

Table 2. Defects and disorders related to water supply in vegetables and small fruits. [1]

Crop	Defect or Disorder	Water supply Excess (+) Deficit (-)
Beet	growth cracks	- followed by +
Cabbage	burst heads	+
Carrot	growth cracks	- followed by +
Carrot	forked roots	-
Carrot	misshapen roots	-
Carrot	poor color	+
Cauliflower	ricey curds	-
Celery	blackheart	-
Cucumber	point ends & crooked fruits	-
Corn (sweet)	poor ear fill	-
Lettuce	tough leaves	-
Lettuce	burst heads	+
Muskmelon	growth cracks	+
Pepper	blossom end rot	-
Potato	second growth	- followed by +
Potato	large lenticels	+
Potato	misshapen	-
Potato	hollow heart	- followed by +
Raspberry	seedy fruit	-
Snap Bean	poor pod fill	-
Snap Bean	interlocular cavitation	+
Sweet Potato	misshapen and small roots	-
Strawberry	misshapen berries	-

Table 2 (continued)

Crop	Defect or Disorder	Water Supply Excess (+) Deficit (-)
Strawberry	kernal end	-
Summer squash	pointed fruit	-
Summer squash	blossom end rot	-
Tomato	blossom end rot	-
Tomato	blotchy ripening	+
Tomato	radials concentric cracks	- followed by +
Watermelon	blossom end rot	-

1/ After a compilation from various sources by Sanders.

A recent explanation of the effect of balance is found in Lee's work (45) with the collapse of the interlocular parenchyma tissue of green bean pods, called interlocular cavitation (IC). Interlocular cavitation presents a real problem for the processing industry, for this collapse contributes to sloughing and other problems in the canned product. When high rates of irrigation were applied post anthesis, green beans developed IC in direct relation to irrigation frequency. Predisposition to the disorder was found in young pods only a few days after anthesis.

Water deficit decreases filling of pods, in peas and green beans and lessen the development of alcohol insoluble solids and fiber (35, 75).

Water deficit compounded with reduced uptake of calcium was found to increase blossom-end rot in tomatoes (9). Similarly 'ricey curd' of cauliflower increased with soil suction and induced molybdenum deficiency

(3). Cannell *et al* (8) found the incidence of blackheart in celery was often associated with calcium deficiency generated by water deficit. Another complex disorder, blotchy ripening of tomatoes which is associated with potassium metabolism, was also increased by condition of increased atmospheric stress (9).

The processing quality, i.e., pH, total acidity, soluble solids, total solids and color development of tomatoes was enhanced by dry soil conditions, but at the expense of yield (82, 90). Apparently a dilution effect occurs with greater hydration. Carrots responded similarly by dilution in color, soluble solids, and total solids (5). However, increased irrigation caused an increase in the content of capsaicin in peppers (58).

Hollow heart in potatoes has been associated with many environmental factors, including excess moisture. Evaporative cooling (EC) irrigation resulting in high soil moisture enhanced this disorder (72). Evaporative cooling increased secondary growth due to imbalance of moisture supply (60, 61). Low soil moisture has been both implicated and exonerated in reducing total solids in potatoes (15, 65, 74).

YIELD RESPONSE TO WATER DEFICIT

As a prelude to this discussion, it is appropriate to recall Gates' remark in 1968: "as most research has been biased toward description of factors that influence plant growth rather than toward analysis of growth response, it is remarkable that the parameters of the role of water in plant development can be suggested to the present extent. The descriptive approach that avoids analysis of the problem has long gone in a number of kindred sciences and has little place in further study of plant water relations" (26). Some noteworthy improvements have been made in this direction. They will be discussed later, but for the most part, work remains descriptive.

Sweet potatoes are among the few vegetables which seem to be rather drought tolerant. Jones (38) found no increase in yield as long as the available soil moisture (ASM) was maintained above 20%. Similarly, Lana and Peterson (44) could not enhance crop yield with ASM greater than 50%.

In other vegetables borne beneath the soil surface, moisture supply is important. Potatoes were found to yield best when ASM was not allowed to drop below 50% (6, 7, 23, 24, 35), but others have shown an increase in yield with irrigation applied when ASM dropped only to between 60-75% (37, 77, 85).

Onions were also found to respond to irrigation at 80% ASM or -0.3 bars (37). Carrots also needed large amounts of water (1-5"/week) for maximum yield (5).

Takatori et al (76) found an actual yield increase in asparagus irrigated at -0.4 bars while fern growth was enhanced. Allowing soil water potential to drop to -0.8 bars was not harmful to yield.

Jones (36) found irrigation must be applied to celery when ASM reaches 40% if yield reductions are to be averted.

Sweet corn ear size and number of marketable ears were reduced when soil moisture was dropped below 50% ASM (48).

Vine crops, i.e., melons and cucumbers are responsive to irrigation even though they have rather extensive lateral root systems. Tschape (78) noted strong depression in photosynthesis in cucumbers due to internal moisture stress caused by low soil temperature.

Yield of beans, (25, 41, 79) green peas (75) and field peas (49) was increased by irrigation when ASM dropped below 50%. Conflicting evidence is presented as to the critical period of growth and development of the plant water stress which is detrimental to yield. In any case the soil's moisture holding capacity should be taken into consideration. But all findings do confirm the critical need for good soil moisture supply during flowering and to a lesser extent pod development.

In a year of high atmospheric demand, Carolus et al (9) found tomato fruit number and size could be increased 47 to 49% respectively when soil moisture was replenished at 80% ASM. However, Wright et al (90) found irrigation at -0.7 bars reduced yield of tomatoes. Wang (84) in turn found the yield of tomatoes had an optimum range of response to water.

Strawberries yielded more under sprinkler irrigation than furrow irrigation. Sprinkler irrigation resulting in high level of soil moisture tended to increase rotten fruit but this problem was more than compensated for by an increase yield (8). Both Simons (73) and Judkins (39) noted increased yield with increased moisture supply, but the former also noted increased yield with increased moisture supply, but the former also noted reduced runner production when irrigation was applied during the bud formation period.

Excess water can also be harmful as illustrated by the work of Wang (84) who found tomato yields were reduced during years when rainfall exceeded a certain rate (Fig.2). Williamson (89) found absolutely no yield from green beans when the water table was maintained at 15 cm. Further, he found that as the water table was maintained at lower levels, yields increased until the level was dropped to 61-76 cm.

CRITICAL PERIOD OF NEED

Salter and Goode (87) have reviewed the literature extensively on the critical periods of need. Suffice to say as indicated by their review and other works (18, 25, 37, 41, 46, 47) that the critical periods of need

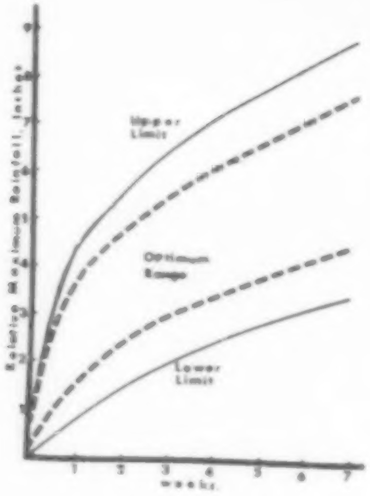

Fig. 2. Relative maximum rainfall in successive weeks versus tomato yield, in central Delaware 1948-1958. After Wang (84)

coincide with the manufacture of the succulent, edible parts. This may be at the flowering stage if flowers or fruits are the edible parts or at cell extension stage if vegetative tissue, such as roots, tubers or stems are the edible parts.

WHEN TO IRRIGATE

Many techniques are available to determine the timing of irrigation. One of the oldest which still has some merit is based on visual observation. This method requires some training but is an 'art' as opposed to a 'science'!

A set schedule which matches mean potential evapotranspiration is often used. This method allows the prediction of the expected need on the basis of the present need (Fig. 3). Unfortunately, it does not take into account different stages of crop need or actual loss (12).

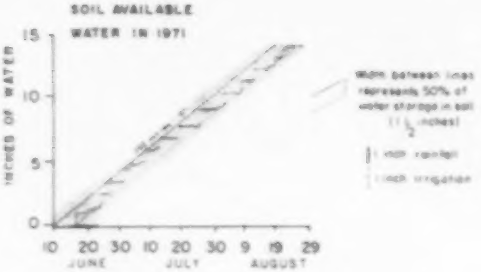

Fig. 3. Record of use and water need in potatoes. After Chase (12)

The use of a sensor such as a tensiometer or gypsum block also has merit. It does require on the spot check and has some drawbacks inherent to the sensors and measures only the soil water potential.

The use of class "A" pan evaporation data has been used very effectively in Washington State (31). It must also be adjusted to suit specific crops and stages of growth. But, in areas of high rainfall, runoff and percolation are not accounted for.

Martin and Nelson (50) have developed a model for prediction soil moisture levels based on soil properties, evaporation, duration and intensity of precipitation. This model can be very useful in projecting irrigation need. Fig. 4 depicts a typical curve for an entire growing season for tomatoes.

Allen and Lambert's model (4) combines crop production, ASM, economic and weather forecast data in a probability framework for use in irrigation scheduling.

The concept of stress day index (SDI) developed by Hiler and his coworkers at Texas A&M University has great import in optimizing both economics of crop production and water use (32, 33, 34).

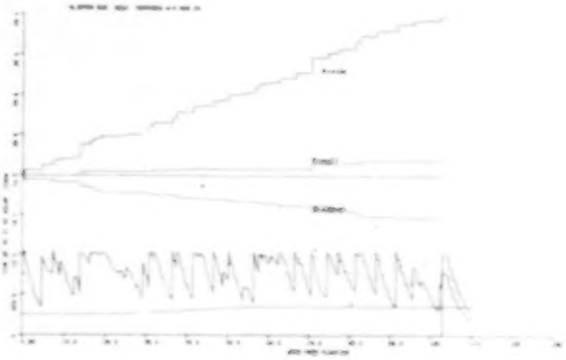

Fig. 4. Precipitation, runoff, drainage and soil water throughout a growing season as estimated from evaporative data. After Martin and Nelson (50).

The equation for determination of the SDI is as follows:

$$SDI = \sum_{i=1}^{n} (CS_i \times SD_i)$$

SDI = Stress day index

CS_i = Crop susceptibility at stage i.

SD = Stress day factor i.e. the degree duration of water deficit

n = Number of growth periods considered.

$$CS_i = \frac{Ty - Sy_i}{Ty}$$

Ty = Total yield under no stress applied.

Sy_i = Yield as a result of stress to a predetermined level at stage i

This technique can be used with any crop and merely requires development of background data. SDI was compared with use of soil water potential (Ψ_s) or plant water potential (Ψ_1) for sorghum. It is more efficient than Ψ_s and Ψ_1 in increasing water use efficiency (Table 3).

For southern peas CS was found to be 0.13 for vegetative period preceding flowering, 0.46 during flowering and early pod fill and 0.43 during pod development. Furthermore, the yield of dry peas was found to be equal to -0.025 (SDI) + 11.61 (Fig. 5) while total dry matter yield was equal to -0.046 (SDI) + 24.94. Thus those indicating different organs have different response with respect to the SDI.

Table 3. Yield and water use efficiency as affected by three methods of scheduling irrigation for sorghum. 1/

Timing Methods	Irrigation water Applied (inches)	Yield Pounds/A	Water Use Efficiency	Percentage Increase With SDI
Soil Water Potential	10.6	6060	0.25	-
Plant Water Potential	12.8	7730	0.25	-
Stress Day Index	7.5	7780	0.41	65

1/

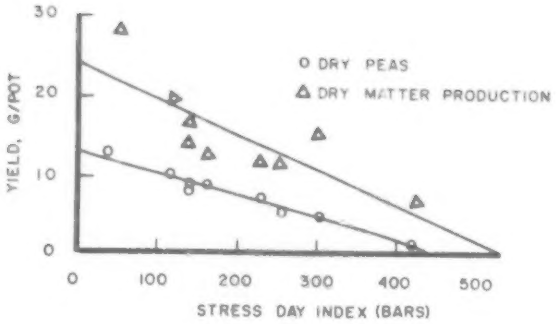

Fig. 5. Yield and variations with stress-day index. After Hiler et al (34).

FACTORS INFLUENCING PLANT DEFICIT AND PLANT RESPONSE

The Ψs certainly has to be considered as one of the most important factors controlling Ψ1. Several workers have shown that Ψs is highly correlated with Ψ1 (19, 30, 33, 51). Epstein and Grant (19) found the water potential of potato tubers (Ψt) was related to Ψs as follows: $\Psi t = +5.231 + 2.463 \text{ Log } \Psi s$. Further potatoes exhibited stress at Ψs below -.25 bars.

Millar and Gardner (53) found dry matter production and transpiration rate of snap beans were positively curvalinearly related to Ψ1 (Fig. 6). As seen in Fig. 7, dry matter production rate increased more rapidly than transpiration rate and stomatal closure, thus indicating that water stress reduced growth more than transpiration. This would explain the lack of relationship between diffusive resistance and plant water potential (19, 34, 52).

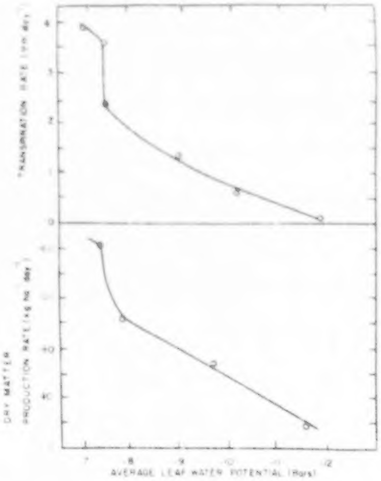

Fig. 6. Transiration rate and dry matter production rate of snap beans as a function of the day time average leaf-water potential. Millar and Gardner (52).

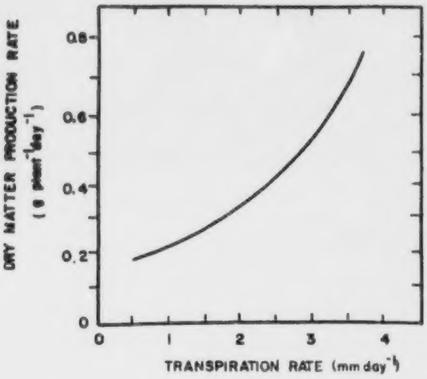

Fig. 7. Dry matter production rate of snap beans as a function of the transpiration rate. Maillar and Gardner (52)

Environmental factors such as wind, temperature, total and net radiation, contribute to evaporation and transpirational losses. Rosenbert (59) has shown that wind breaks can reduce evaporation. Further, plant type is certainly important in evapotranspiration (ET) loss (Fig. 8). Pruitt et al (57) noted that ET of tomatoes exceeded that of any other crop tested even though they never reached complete soil surface cover. At times, ET of tomatoes exceeded that of grass cover by 25%.

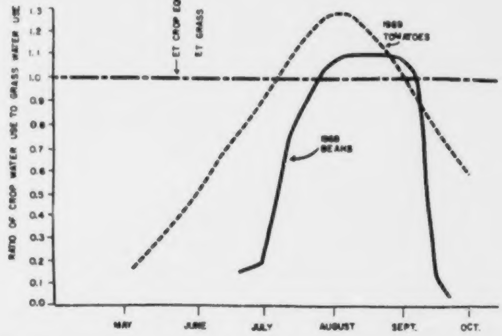

Fig. 8. Generalized curves for ratio of crop evapotranspiration for beans and tomatoes to that for grass. Pruitt et al (57).

OPTIMIZATION OF PLANT-WATER STATUS

Antitranspirants

The use of chemicals which cause stomatal closure and/or increase resistance to water diffusion has shown potential in recent years. Some of the important considerations of this means of water management are discussed by Waggoner (83). Growth retardants such as CCC and SADH have been shown to reduce transpiration in green beans (Fig. 9) and other crops (40, 43, 56, 68). Other antitranspirants have been shown to reduce stress in almonds and olives (15, 16).

Waxes and reflectants have also been found to be of value in reducing transpiration losses (1, 15).

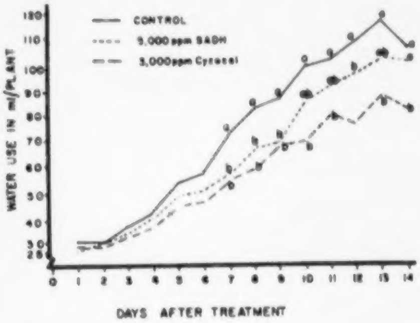

Fig. 9. Water use of green bean plants over several days as influenced by SADH and Cycocel. After Sanders and Nyland (68).

Trickle or Drip Irrigation

As Dr. Phene has discussed earlier in this symposium, the trickle or drip irrigation system consists of applying a low volume of water directly to the base of the plant via various metering devices. This system has real merit in maximizing water use and improving yield of many crops (2, 28).

Impermeable Barrier

The use of an asphalt moisture barrier to reduce the rate of water percolation in deep sandy soils has shown real promise. However, irrigation must also be used with the barrier in many areas (20, 72). Cabbage, snap beans, sweet corn, tomatoes and sweet potatoes have benefited from the use of such a barrier. The yields of tomatoes and sweet potatoes was enhanced over the non-irrigated control by irrigation alone, the barrier alone or a combination of both (Table 4). Further, the water use efficiency was also improved in a similar manner (Table 5).

Table 4. Water-use efficiency of sweet potatoes and tomatoes as affected by asphalt barrier. 1/

	Water-Use Efficiency in cwt/A/in.	
Treatment	Sweet Potato	Tomato
None	5.4	6.0
Irrigation	5.2	8.3
Barrier	9.5	15.5
Barrier + Irrigation	8.5	11.4

1/ After Saxena et al (71)

Table 5. Yield of sweet potatoes and tomatoes as affected by asphalt moisture barrier. 1/

	Marketable yield (cwt/A)	
Treatment	Sweet Potato	Tomato
None	107	99
Irrigation	121	163
Barrier	188	256
Barrier + Irrigation	197	222

1/ After Saxena et al (71)

Evaporative Cooling Irrigation

Up to this point, the application of water via the soil in an effort to maintain the plant at relatively high Ψ in order to maximize growth has been the object of our discussion. However, environmental demand often exceeds the plant's ability to keep itself hydrated. As a result, significantly low Ψ_1 is associated with a concomitant reduction in yield. This environmental demand is increased by an increase in air temperature, transpiration and relative humidity. We found leaf temperatures may exceed air temperature by as much as 7-10°C.

Kramer (42) suggested midday sprinkling as an efficient transpiration deterrent.

Factors influencing evapotranspiration after sprinkling were as follows: droplet size, application rate, crop type, crop height, soil moisture tension and water temperature (21). It was also found that wet leaves had equal or less evapotranspiration than dry ones. Further, evapotranspiration (21, 22).

McMillan and Burgy (51) found no difference in evapotranspiration of wetted and non-wetted grass surfaces. In addition evapotranspiration from leaf surface, in part, replaced normal transpiration.

Van Den Brink and Carolus (81) demonstrated a marked decline in ambient and soil temperature, ranging from 5-8°C and 1-12°C respectively, during a normal irrigation of a tomato field. It was suggested that EC might be a very useful tool in reducing plant water stress (9). Soil surfaces may attain temperatures reaching 23°C in excess of air temperature resulting in burning of young seedlings (86).

EC can also be a means of improving stands of young seedlings (10). Our own work indicates that stands of snap beans planted in mid July could be increased up to 25% to 75% using EC.

Cuthbert (14) found EC did not affect the fresh or dry weight of leaves, nor the flower number in summer squash, but did increase relative leaf area. Further, the cooling of plants increased the size of the cotyledons. This response was similar to that of soil moisture level increasing from 20 to 89% field capacity.

Gary (29) has reported EC has reduced blossom drop in walnuts, almonds, cherries, pole beans, strawberries, prunes and grapes.

Chesness and Brad (13) reported temperatures in a strawberry planting of 48,38, and 42°C for leaf, air, and soil respectively. After application of .08 inch/hour of irrigation in 30 minutes the respective temperatures had decreased 15, 9 and 3°C. An increase of 55% in strawberry yield was obtained with irrigation equivalent to only 2 inches of water (87).

Grapes is another crop which has shown favorable response to EC. Gilbert et al (27) noted reduction of air, leaf and berry temperature of 5, 9-14 and 5-7°C respectively. Further, an increase in yield was accompanied by an increase in quality, i.e., pH, sugar/acid, and total acid. Williams (88) noted yield increased in tokay grapes from 8 to 12 T/A in 1967 and 6 to 16 T/A in 1968 with increase of 50% in quality.

Sanders and Nylund (62) measured leaf temperature reductions of 20°C in potatoes on a day of high radiant energy (Fig. 10). Further, leaf temperature increased as water evaporated from leaf surfaces but never reached non-cooled leaf temperature (Fig. 11). Schaefer (72) found potato leaves reached pre-misted temperature in 20 minutes after water application under a lower temperature (31°C). However, when the temperature was raised to 39°C, it required only 10 minutes for leaves to return to their pre-misted temperature.

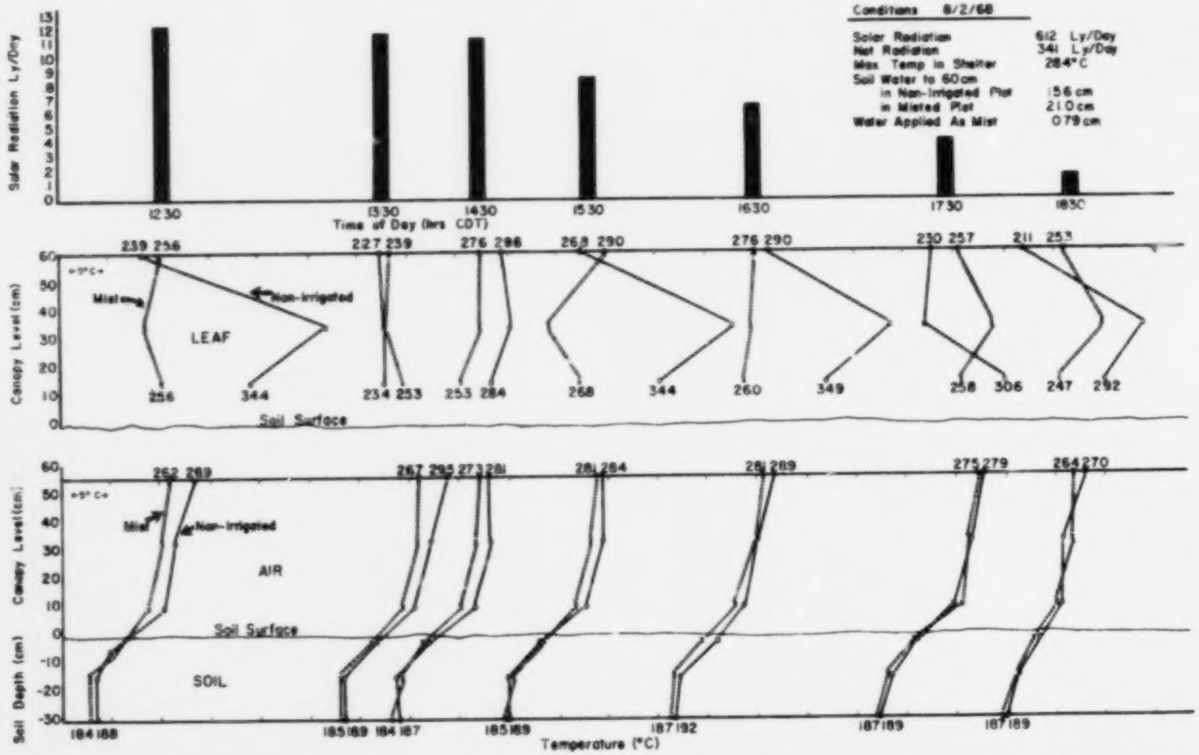

Fig. 10. Leaf and air temperatures within and soil temperatures below misted and non-irrigated potato canopies and incident radiant energy flux during a day of high total radiation (8/2/68). After Sanders and Nylund (62).

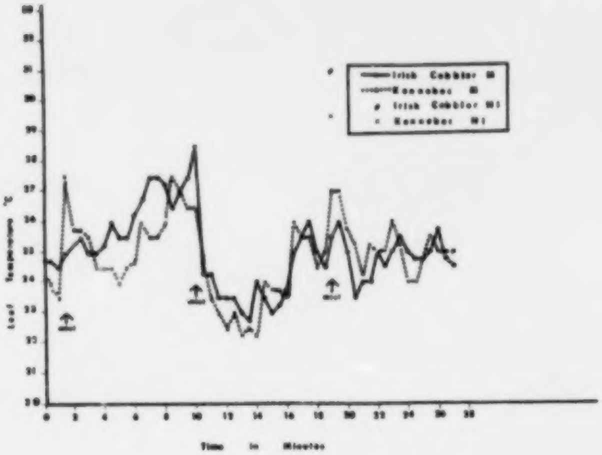

Fig. 11. Leaf temperatures of Irish Cobbler and Kennebec potato leaves during three misting cycles after 3.5 hrs. of misting with leaf temperature of non-irrigated leaves as reference. After Sanders and Nylund (62).

Sanders _et_ _al_ (67) found the air temperature in a snap bean field was reduced as much as 15°C by EC (Fig. 12).

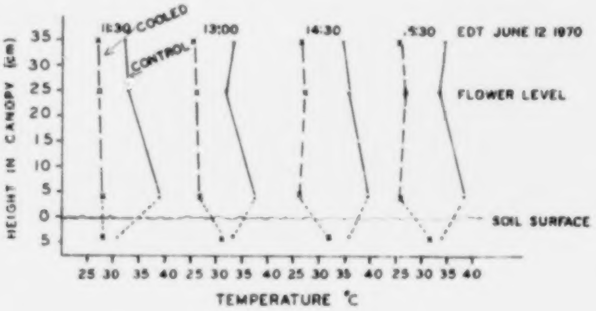

Fig. 12. Air and soil temperature at several levels in a snap bean canopy as affected by evaporative cooling, June 12, 1970, McCain, N. C. Sanders _et_ _al_ (67).

The yield of potatoes was increased by EC in some instances, expecially under conditions of high environmental stress (11, 55, 63). Total solids of potatoes were both increased (54, 55) and (65) by EC. This was primarily due to greater water holding capacity of the soil in the latter instance.

Sanders and Nylund (62) found EC reduced the rate of change in leaf hydration as indicated by relative water content (Fig. 11). It delayed reduction in relative water content of leaves. Nylund (85) found that plants subjected to the EC did not produce an increase in yield of potatoes and snap beans with EC, but he obtained equal yield and a later maturing crop with 5" less of water. In another study, snap bean yields were increased by 48% under EC (86).

Our work with EC in North Carolina on tomatoes has not resulted in any changes in yield or quality. However, a dramatic decrease in fruit and leaf temperatures has been observed (Fig. 13).

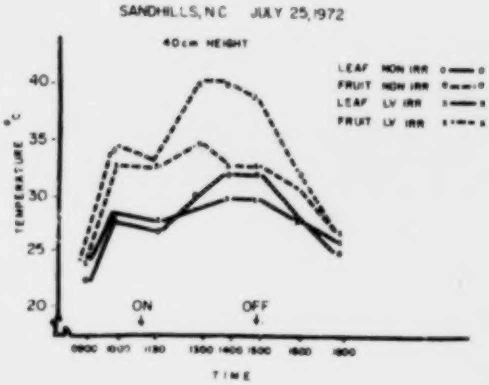

Fig. 13. Leaf and fruit temperature of tomatoes at 40 cm above the soil surface as affected by Evaporative Cooling during a summer day (July 25, 1972.)

In a deep sandy soil in North Carolina, increased plant growth of snap beans had been observed (Fig. 14). Further, EC resulted in increased

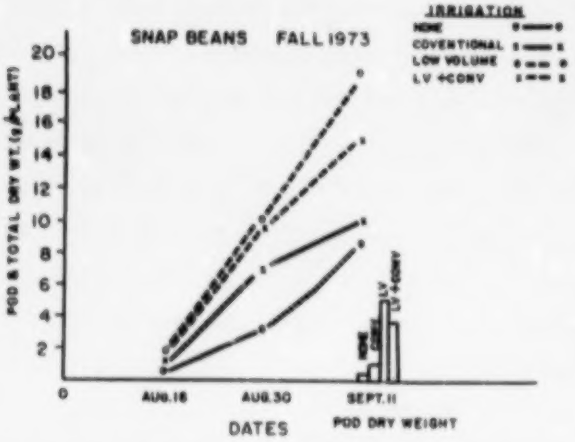

Fig. 14. Plant and pod bean growth dry weight of snap beans as influenced by irrigation treatment, Fall 1973. Sandhills, N. C.

yield under high environmental demand conditions. Whenever the mean air temperature exceeds 74°F, yield was increased by EC (Table 6). In spring 1973, yield was more enhanced by conventional irrigation than by EC alone; due to a need for soil moisture. In the fall 1973, EC increased earliness by 7 days. Early production at this particular time has great economic import, because harvest at this time (early Sept.) coincides with a low supply of snap beans on the market.

Sanders _et al_ (64) found marked changes in the mineral status of EC plants. Zinc content of potato leaves and petioles was increased from 2 to 5 times at various periods (Table 7). This element is known to affect auxin metabolism, thus indirectly affecting cell enlargement. Phosphorous content was also higher in plants subjected to EC and remained high later in the season. This retention of P would explain the maintenance of potato plants later in the season. Carolus (10) also noted marked changes in N, P, K, Ca and Zn in tomatoes under Ec conditions.

Table 6. Snap bean yield as affected by irrigation practice during several seasons.

Irrigation treatment	YIELD T/A					
	'71Spring	'71Fall	'72Spring	'72Fall	'73Spring	'73Fall
None	1.84	2.36	2.19	1.25	2.60	0.66
Conventional	2.54	2.35	2.28	1.76	6.41	2.72
Evap. Cooling	3.29	2.39	2.21	5.49	3.82	1.90
Evap. Cooling + conventional	2.62	1.66	2.04	5.10	6.84	2.89
LSD .05	1.10	ns	ns	1.14	1.17	1.85
Mean temp.	74.58	71.90	68.88	76.58	75.30	77.85
Max. temp.	95	90	91	96	94	95
Precip.	8.26	7.46	10.89	4.76	5.71	5.71

The rate of photosynthate accumulation, as well as incorporation of $^{14}CO_2$ into soluble amino acids in the tubers were favorably affected by EC. Haulm portions of the potato plant responded favorably to EC also.

Summary

We have discussed the fact that vegetables and small fruits are very succulent products and a high state of turgidity is essential for maintenance of quality. Water balance is very important, for in many crops both deficit and/or excess of water have impact on yield and quality characteristics. The soil water potential through its effects on plant water potentials is very important. The loss of water via transpiration is intregally related to environmental conditions and; soil and plant water potential. Transpiration cannot be considered a "necessary evil", but

Table 7. Zinc content of potato blades and petioles as influences by methods of irrigation on three sampling dates during each of three years. 1/

	Zinc content on indicated days after emergency in each of 3 yrs.								
	1967			1968			1969		
	47	62	80	51	69	93	44	58	83
Irrigation	Total Zn in leaves (ppm DW)								
None	39	87	44	38	64	31	33	35	32
Furrow	68	110	45	36	84	39	33	32	36
Mist	96	226	117	170	184	168	87	108	84
Mist & Furrow	99	187	134	157	173	106	86	123	88
hsd (.1)	48	90	50	126	104	98	30	32	30
	Total Zn in petioles (ppm DW)								
None	38	44	44	39	50	30	34	40	30
Furrow	31	42	36	48	34	48	58	35	27
Mist	52	84	67	69	125	62	62	54	45
Mist & Furrow	43	103	75	78	118	61	54	62	43
hsd (.1)	15	15	23	36	104	ns	ns	27	12

1/ After Sanders et al (64)

should be kept at a reasonable level for optimum plant growth.

Water deficit can be reduced with conventional irrigation, antitranspirants, trickle irrigation and evaporative cooling. Evaporative cooling can be used to regulate growth, increase plant stand, increase yield by reducing plant stress, and alter the plant's metabolism. Evaporative cooling can be used as a shunt of the plant's water cycle. By reducing energy load on the plant, it reduces the harmful decrease in plant water potential.

New techniques based on plant and soil moisture conditions are becoming available for determining the timing of irrigation. Stress day index and the use of evaporation data are very important new concepts. These new methods coupled with new measurement techniques for plant water potential will contribute to an efficient use of the water by the plant for optimum growth and yield.

On the basis of the previous discussion, it is the opinion of the authors that the following research problem areas deserve further investigation:

a. Determination of critical stage of plant growth and timing for use of irrigation for optimum plant stand, yield and quality.

b. Determination of more effective techniques and timing for increasing water use efficiency through antitranspirant, trickle irrigation, impermeable barrier and evaporative cooling.

c. Possible effect of growth regulators in optimizing water absorption and utilization by some vegetable and small fruit crops.

d. Plant population, irrigation method and their interaction with optimum nutrient levels for maximum yield and optimum quality of vegetables and small fruits.

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PUBLIC AND PRIVATE RIGHTS RELATED TO WATER USE

Clyde F. Kiker

Rights are granted by society and, because of the dynamic nature of society, are constantly changing. Typical are the rights to use water for both private and public purposes. Initially water was common property with the rights to use vested in all people. In the eastern United States during the nineteenth century riparian common law doctrine was applied to meet the needs of an increasingly complex society.

During the mid-twentieth century intense pressure has been exerted on the water resources and many eastern states have looked to statutory control of water resources. The Florida Water Resource Act of 1972 is typical and changes many rights enunciated under riparian doctrine. Whereas riparian doctrine dealt primarily with the individual's right to water use, the legislation injects strong public interest considerations.

The major effect on water rights comes in the form of required permits for all consumptive uses, all waste disposal and all physical modifications of the water resource system. As to whether the public and private water rights are enhanced or curbed will depend upon the ability of the water management district, the political and administrative unit governing the system, to technically and equitable operate the permit system.

(Key words: Water rights; riparian doctrine; water control legislation; water management; water use permits.)

Chapter 21

PUBLIC AND PRIVATE RIGHTS RELATED TO WATER USE

Clyde F. Kiker[*]

"Rights may be defined as socially - sanctioned decision-making powers: decisions concern action, the power to do, or to refrain from doing something with respect to things, or individuals, or groups of individuals" [4, p. 149]. Thus Dales defined rights. In our case, the things are water and its uses, and the individuals or groups are the users. Water can be many things: to the shippers it is a highway, to the power utilities it is a source of energy, to the agriculturalist it is a factor of production, to the industrialist it can be both an input to production and means of waste disposal, to fish and wildlife it is their habitat, to residents of flood plains it can be a source of much misery and loss, while to others it is a source of joy and beauty. Since not all these uses are compatible, society must have a systematic, equitable way of determining who has the decision-making power over the use of water.

The purpose of this paper is to trace through the public and private rights to water use. Since rights are a reflection of societal attitudes which are constantly changing, the rights to water and its use are dynamic. I will first consider property rights in their broadest definition and then narrow to consider rights in water specifically. The major emphasis will be on riparian common law doctrine that is used in the eastern states. Following this I will deal with the recent move to codify many aspects of water use through the legislative process. I will conclude by considering the effect of administrative edicts (rules and procedures) on water rights.

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Water Rights

Before turning to water rights specifically let us consider a spectrum of rights in property. First, we can define a form of rights which "confers on whoever owns an asset exclusive rights to use it plus a right to transfer its exclusive use to another person" [4, p. 150]. These have been termed "private property rights" and will be at one extreme of the spectrum. This concept has been the basis of our market system, for once an exclusive property right has been established, the price system automatically handles the allocation of the asset and its services. This type of right works best when applied to the use of assets that are physically divisible and whose use do not involve significant effects on other individuals or the utility of other property objects.

A second form of rights in property, generally termed "common property rights", is at the opposite end of the spectrum from private property rights. Common property rights are non-exclusive and non-transferable, the rights to use an asset being vested equally in each citizen, i.e., allocation is on a "first come-first served" basis

[4, p. 151]. Air, water, public rangeland, forests, roadways, oceans, etc. have historically been considered common property. In recent times control of some of these has been assigned to, and property rights conferred upon, individuals. Others, primarily water, air and the oceans, have been overused or used inappropriately causing deterioration in quality.

Lying along the spectrum between the two extremes of private property rights and common property rights are the vast majority of rights to assets use. Two characteristics common to this broad range, are exclusivity and non-transferability. Exclusive rights to the use of an asset are assigned on the basis of meeting certain eligibility requirements. Hence, Dales called these "status rights" [4, p. 152]. Because of the non-transferability of these rights to asset use, the price system cannot be used for allocation. Rather, the allocation is made by administrative fiat or direct legislation.

In our consideration the services of water could be declared common property rights with usage open to all on an equal basis. Or they could be assigned as private property rights with use being dependent upon purchase of a "user permit" issued by the government but saleable to other individuals [4, p. 152]. Or last, entitlement to their use could be based on meeting certain eligibility conditions and be handled by the government as status rights. We will next look at water rights as they have been conferred in our nation in the light of these ideal categories.

The states of the Union have each evolved systems of law under which the acquisition, use and protection of water rights are controlled and regulated. The humid eastern states[1] evolved the "riparian doctrine" while the arid western states[2] adopted an "appropriation doctrine" and several states[3] chose to recognize both doctrines. The basis for this springs from the imperium reserved to the states in the Tenth Amendment to the Federal Constitution. Although the state governments have the greatest scope of powers relating to water rights, the federal government has substantial influence over water use based on several constitutional powers.[4] The major emphasis in this paper will be on state actions and their influence on water rights.

Water in areas with abundant supplies has been historically considered to be common property. During Roman times water was "...res nullius, the property of everyone" [9, p. 166]. and in early England the water was considered similarly. The industrial revolution brought about change. The courts recognized a need for a stable water use doctrine and evolved the riparian doctrine which was to be adopted by the eastern states of United States. Owners of property rights to land adjoining a lake or stream, riparian land, were entitled to the full natural flow of the stream without change in quality or quantity. Others were entitled to use the waters for fishing and navigation. Taken literally the doctrine would preclude removing water from or depositing any foreign substance into the stream. The riparian doctrine was a part of common law and when conflicts over water use arose they were settled by civil litigation, rather than avoided through regulation under the police power.

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[1] States east of the Dakotas, Nebraska and Kansas.

[2] Alaska, Arizona, Colorado, Idaho, Nevada, New Mexico, Utah, and Wyoming.

[3] California, Oregon, Washington, Kansas, Nebraska, North Dakota, South Dakota, Oklahoma, and Texas.

[4] Commerce-navigation powers, proprietary powers, war power, admiralty, treaty power, general welfare power and control of interstate relations [1, p. 66].

In the United States the doctrine has been modified case by case through the process of case law in the state courts to entitle the user to make reasonable use of water for any purpose not unduly interfering with the reasonable use of other riparian users. Assuming an ample supply of water this form of the riparian doctrine should facilitate adjustment of conflicts between users in accordance with the demands of each user and the dictates of the general public interests. In theory the reasonableness rule, administered by the courts, provides each riparian[5] with a certain degree of flexibility which allows new uses or expansion of present uses in the light of changing conditions of water use and supply. Generally in the riparian states prior to the twentieth century the population densities were so low that the available water was more than sufficient to meet the consumptive demands of riparian owners and there were few limitations brought on by the reasonableness rule.[6] Likewise, the stream flows were normally sufficient to assimilate the waste materials that were dumped into the stream and some change in water quality was tolerated and deemed part of water rights.

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[5] Riparian is used to connote an owner of riparian land.

As populations grew and society became more complex criticism was leveled at the riparian system because it often indirectly prevented more efficient use of the water resources of a state. Efficiency is not normally required at common law, and is only considered when other riparians are injured. The courts normally limit their considerations to the interests of the litigants before them, and not the public interest. It is illegal under the doctrine to divert water for use on nonriparian land. The doctrine restricts stream water to use on riparian lands by riparian owners. The result is if more water is normally available in a watercourse than is needed for use on riparian land, the remainder goes to waste. Frequently better use may be made at other places by riparian or nonriparian owners.[7]

Elements of uncertainty are associated with the reasonable use of water for nondomestic purpose. Social values change the concept of reasonableness; what was reasonable only a few years ago may be unreasonable today. The reasonableness of each use is determined by the needs of other riparian owners and unforeseen conditions can arise when others commence or expand uses despite long nonuse of their rights. The reasonableness of a present use may be altered by addition of a large number of the same uses which would make the total use unreasonable. This is especially true in the case of waste disposal where the assimilative capacity of a stream may be easily overused. In addition, riparians not making use of water can enjoin an existing use as unreasonable with regard to his right. The extent of a riparian owner's right of reasonable use can only be determined by expensive litigation often of long duration. The resulting uncertainty causes needless loss when water use patterns of established industries are upset by later competing uses. Similarly, and perhaps of greater economic consequence, water goes unused or is devoted to less valuable uses when industry declines to locate in an area because of the uncertainty of their supply. The courts, recognizing their lack of expertise and the inefficiency of the case-by-case approach, have been reluctant to become involved and have, truly, increased the uncertainty felt by nondomestic water users [9, p. vi].

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[6] Use of underground waters presented no problems and was scarcely covered by either statute or case law.

[7] Features of the appropriation doctrine used in the more arid states partially circumvented this problem.

Population growth and technological development in agriculture and industry have placed greater demands on the water resources of the riparian states. Maintenance of stream flows, ground water levels[8] and water quality has become increasingly difficult. Concern over the adequacy of the common law case-by-case approach has led many states to move to statutory means of dealing with water quantity and quality problems. The Florida Water Resource Act of 1972 and other earlier legislation has provided Florida with a comprehensive water law that has many of the features found in other states' legislation or is likely to appear in the near future.[9] Next, we will examine some of these features and the effect they have on public and private rights in water.

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[8] The reasonableness rule has been applied to ground water in the riparian doctrine states, but as in the surface water case has not been sufficient to handle quantity and quality problems.

Statutory Regulation of Water Resources

The move to statutory regulation of a state's water resources is not intended to infringe on the individual's and public's rights to use water, but rather to enhance them by taking into consideration the hydrologic interrelationship of all types of water, minimizing uncertainty, and providing flexibility that will allow maximum beneficial use of water and eliminate waste. The Florida Water Resource Act of 1972 [5] is a case in point. It modified certain aspects, but does not displace the basic intentions of the riparian doctrine.

The Florida act authorizes a state water plan and establishes a two-tiered state and local administrative structure for implementing its provisions. A state natural resources agency exercises a coordinating and planning role while actual administration at the local level is delegated to five water management districts established along hydrologic lines. Each water management district will be governed by a Governing Board of nine residents of the district appointed by the Governor to a four year term and confirmed by the Senate. A permit system is used as a means to regulate consumptive uses of both surface and ground water, and provisions are made for competing applications and regulation in periods of water shortages. Regulation of wells, dams, impoundments and surface water control structures is required. Inventory provisions are established in order to give water management districts knowledge of their water resources as a basis for control over works affecting them. Water quality management has been provided for in other statutes. The intent is to provide for the management of water for efficient use and conservation as well as for protection of natural resources, fish and wildlife, and public health and welfare [5].

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[9] A model water code has been prepared by Maloney, Ausness and Morris [9] and presents all of the considerations in the Florida act plus others.

More specifically, the act declares that "...all waters in the state are subject to regulation..." [5, Part 1, § 4 (1)] where waters in the state are defined as "...any and all water on or beneath the surface of the ground or in the atmosphere... as well as all coastal waters within the jurisdiction of the state..." [5, Part 1, § 3 (9)]. The states water resources will be studied and a state water use plan developed. In formulating the plan the Department of Natural Resources and water management districts will give consideration to the attain-ment of maximum reasonable-beneficial[10] use of water; the maximum economic development of water resources consistent with other uses; the control of such water for such purposes as environmental protection, drainage, flood control and water storage; the quantity of water available for application to a reasonable-beneficial use; the preservation and enhancement of water quality; and the requirements of public recreation and the protection of fish and wildlife [5, Part I, § 6 (2), (8)]. The districts will implement the plans through regulation and control of the waters of the districts.

The heart of the water regulation is a permit system administered by the Governing Boards of the water management districts. Essentially there are two types of permits, regulatory permits and consumptive use permits. The regulatory permits provide control over future modification of the water resource system. Initially an inventory of the surface and ground water resources including information on all existing wells, dams, impoundments, diversions, and water management structures, will be made. Thereafter, permits will be required for well drilling and installation of pumping equipment, for alteration or construction of all types of water control and impoundment structures, and for sewage treatment plants and waste water disposal [5, Parts III & IV].

A consumptive use permit must be obtained for removal of water from all sources and for all uses except domestic consumption by individuals. For a permit to be granted it must be established that the proposed use is a reasonable-beneficial use, will not interfere with any presently existing legal use, and is consistent with the public interest [5, Part II, § 3 (1)]. The Governing Boards may authorize a permit holder to transport and use ground or surface water beyond overlying land or outside the watershed from which it is taken if the transport and use is consistent with the public interest. The Governing Board may preserve water in an area from consumptive use in order to protect fish and wildlife or the public health and safety. If there is inadequate water for two or more applicants, which otherwise comply with the provisions for receiving permits, the Governing Board may approve or modify the applicants in a manner which best serves the public interest. Permits may be granted for up to twenty years in most cases [5, Part II, § 6, § 7, § 10].

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[10] Reasonable-beneficial use is defined below.

Provisions are made for the Governing Board to impose restrictions on one or more classes of permits when insufficient water is available to meet the requirements of the permit system, or when conditions are such as to require temporary reduction in total use within the area to protect water resources from serious harm. If these actions "... are not sufficient to protect the public health, safety, or welfare, or the health of animals, fish or aquatic life, or a public water supply, or recreational, commercial, industrial, agricultural, or other reasonable uses..." the Governing Board may apportion, rotate, limit, or prohibit the use of the water resources of the district [5, Part II, § 10 (7)]. In determining which permittees shall be restricted the Governing Board should be guided by the standard of public interest and may consider: domestic use has highest priority, users that supply necessities to the population of the area over users not supplying necessities, public users over private users of the same type, and users subject to serious capital loss over users with smaller losses [2, p. 35].

Such legislation has caused a move from a modified common property right in water to a definite status right in water with the general public having predominate consideration. Under the riparian doctrine water use was approached on an individual basis. The owners of property rights to riparian land had a right to use water, but this was not a property right (as we have defined it above) to the water itself. Nonriparians could use the water for navigation and fishing while the riparian could use the water consumptively and for waste disposal as long as his use was reasonably consistent with other riparians' uses. Conflicts were settled through litigation after the fact. The legislation creates a sharp contrast. There are strong statements that water should be managed and used in a manner most beneficial to the public interest. In fact the act defines "reasonable-beneficial use" as "...the use of water in such quantities as is necessary for economic and efficient utilization, for a purpose and in a manner which is both reasonable and consistent with the public interest..." [5, Part I, § 3 (5)].

Whereas before the legislation riparians could use water consumptively or for waste assimilation up to the point where the effect became damaging to another user, now all users, riparian and nonriparians, must obtain permits from the state to use water (domestic water excepted).[11] Riparians and nonriparian may obtain consumptive use permits for water use on riparian and nonriparian land. Likewise, a permit must be obtained to dump any type of material into a water course of lake. The approach is to prevent conflicts before they arise. The requirement is that the use be a "reasonable-beneficial use." This reasonable-beneficial use standard is a merging of concepts from the riparian doctrine and the appropriation doctrine. The reasonable use standard allows the water management districts to permit more productive uses over less productive uses while the beneficial use standard allows them to restrict wasteful uses [8, p. 20].

The intent of the legislation was to enhance present legal water uses by reducing uncertainty, not to curb them. The riparian owner's use of water was highly dependent upon other users and he was never certain of the exact quantity of water he would have to use. This uncertainty prevented efficient use of the available water. Under the permit system a permittee is assured of a particular quantity of water for the duration of the permit. Only in periods of water shortage will it be possible to have the quantity reduced and he will know where his use stands in the order of priorities. Given sufficient hydrologic data his uncertainty can be converted into a definable risk. This increased certainty will allow greater capital investment and more efficient use of the water. Assuming adequate technical support and efficient, fair administration the system will permit higher levels of economic activity in the area and more compatibility of economic activities with the natural system.

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[11] The rights of riparians legally using water as defined in the law, at the time the legislation was passed, were protected by special provisions allowing these uses highest priority in the initial assignment of permits [5, Part II, § 4, (2)].

The legislation acknowledges uses other than economic uses of water. Under the riparian doctrine only uses that had pecuniary effects were recognized. To halt a riparian's use of water, practically it was necessary to establish that the use was causing damage to another riparian in monetary terms. The legislation recognizes the nonmonetary aesthetic value of water and the value of water as fish and wildlife habitat. In fact, it states that water may be reserved from use by permit applicants to protect fish and wildlife [5, Part II, § 3 (3)]. This is a substantial increase in the public's rights related to these uses of water.

For the water management district to actually promote greater efficiency through management and regulation, substantial information on water supplies and demand will be needed. To grant permits for given quantities of water at given locations, whether surface water or ground water, the districts will require accurate information on the potential of the hydrologic and management systems. Stochastic aspects of the area's rainfall will have to be modeled to obtain accurate projections on the availability of water. Models of the aquifer systems will be needed for determining the quantities of ground water in a given area and the effect of additional wells and pumping. Likewise, methods of estimating runoff along with models of the streams and management structures will be needed to determine the quantity of surface water available under varying conditions.

Demand for water can be divided into two categories, water for natural systems and water for economic activities. Presently, little is known about the role water plays in various ecosystems, but if these systems are to be preserved as the legislation requires, a greater research effort will be needed. Similarly, there is little information on the value society places on these natural systems and aesthetics associated with them. To establish water use priorities for various economic uses accurate information on water as a factor of production for different crops and for industrial output will be needed. The economic value of water for recreation must be estimated. Then, of course, there is substantial interaction between the various uses.[12] For example, waste disposal in water is an economic activity that affects the natural system as well as other economic activities such as recreation. Initially it will be difficult to manage water to both stimulate economic activities and to protect the natural resources, but over time accumulation of knowledge should bring about improved ability.

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[12] Simulation models of the rainfall and runoff phenomena, the water management system, and the economic activities occurring in the Kissimmee River basin, part of one of the Florida water management districts, have been incorporated into a water policy evaluation model [7, 10]. Similarly, linear programming has been used to evaluate various water allocations in the same river basin [10].

Concluding Comments

Water rights have been moving along the spectrum of rights. Initially, water was considered by society to be common property with the rights to use vested in all. This led to what Hardin has called "the tragedy of the commons" [6] in that there has been overuse and abuse of surface and ground water. The riparian system, a modified form of common property concept, vests certain water rights in holders of property rights to land contacting water. A riparian could consumptively use water or dispose of waste materials in water so long as his use did not infringe upon the reasonable use of another riparian. Efficiency from society's point of view was not considered. In fact, public interests or rights were not considered except as they were expressed through the rights of individual riparians.

Recently, there has been a move to statutorily modify the riparian system, vest water rights in all the people and authorize the government to represent the peoples' interests. Under the Florida legislation those individuals wishing to remove water, to dump waste materials, or physically modify the water resource system must receive permits from governmental agencies. This in effect changes the rights to water use from those who consumptively use water or dispose of wastes in water to those whose use makes no change in the quantity or quality of the water, recreators, fishermen, wildlife, etc. Rights to water use have become "status rights."[13]

The assumption in this statutory approach is that both public and private rights in water use will be enhanced. Whether this will occur or not will depend upon how well the governmental agency is able to implement the features of the legislation. The water managers will need technical information especially as it relates to the natural supplies of water, the physical water management system, and the demand for water by both economic activities, and the natural systems. But, more important is the great latitude the managers have in allocating the use of water. The Florida legislature provided for "...the management of water... to preserve natural resources,... and ...to promote the general welfare of the people of this state" [5, Part I, § 2 (2)]. There are some guidelines but there remains a great deal of discretionary leeway in interpretation of "public interest". The agencies given this allocative power must make serious efforts to reflect the attitudes of the people in their decisions if the people are to believe the attempts at management are truely in their interests and enhance rather than curb their rights to water use.

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[13] There could be, of course, a further move along the spectrum of rights and establish "private property rights" in water by allowing the government agency to sell exclusive and transferable rights to use water for certain activities. There is a broad gap in knowledge as to what the impacts would be in establishing a market for water rights which must be bridged before making this move.

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Chapter 22

EXPECTATIONS VS. ACHIEVEMENTS: SOME REFLECTIONS ON THE WATER ACT

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It has now been 16 months since the enactment of the Federal Water Pollution Control Act Amendments of 1972. I am delighted to have this opportunity today to discuss the implementation of that far-reaching statute, and in particular the status of the development of effluent guidelines and the National Permit Program.

My remarks, however, go considerably beyond the areas of guidelines and permits. I want to discuss the status of our overall efforts to implement the 1972 Water Act, including problems related to planning and grants. I think such a review is timely and will help you better understand the difficulties involved in administering such an enormously complex program.

Over the past 16 months we have gained a great deal of experience in our efforts to implement the Act. In the light of this experience, it is possible to see some things more clearly now than we, or you, might have been able to see them at the time of enactment. And since we are still at a relatively early stage in the life of the statute, there is ample time to benefit from and apply many of the lessons that can be drawn from this experience.

The 1972 Amendments represented a tremendous step forward in the national commitment to achieve clean water. As you know, the 1972 Act was a complete overhaul of the entire statutory basis for conducting our national water pollution control programs. In every respect, the intent of the Congress was to expand and strengthen these Federal and State programs. Standards were made more demanding, funding was greatly increased, enforcement was beefed up, and a host of research, planning, and other supporting provisions were added. The Act stands as one of the monumental achievements of the environmental thrust of the early 1970's. Its passage culminated years of effort by environmentalists. Its sweeping provisions promised a day when clean water would be a reality.

Although there was less than universal acclaim at its enactment, the "hurrahs" as well as the "boos" for the 1972 Amendments have now echoed into history. We are now well into the implementation of the Act and it is time to take a cold, sober look at the status of implementation. It is now time to ask ourselves, how goes the battle? Will the promise of clean water be fulfilled?

Speaking as only one out of the several thousands of people who have struggled to understand and apply the complex provisions of the 1972 Act, I must confess that after 16 months of effort, I feel a good deal more than 16 months older. I also feel somewhat wiser. On occasion, I even feel a bit sadder.

Speaking somewhat less facetiously, I am impressed by the progress that has been made. But I am even more impressed by the effort that has been expended and scope of the job that still lies ahead. At the outset, I would like to state clearly and candidly that an honest appraisal of our efforts to date cannot overlook the fact that, in many respects, our rate of progress has not permitted us to meet many of the deadlines established in the Act or fulfilled many of the expectations created by the Act. To be sure, the Act requires the Administrator to issue a bewildering number of standards and regulations, typically imposing deadlines of 30, 60, 90, 120, or 180 days after enactment. We have met these deadlines in a few instances, but more often we have missed them. In several instances, law suits have been filed against EPA to require performance, and in some cases court orders setting dates for compliance have been issued. Believe me when I say this is not a happy way to run a program.

To provide some further perspective on this problem, however, it is useful to look briefly at several different facets of the statute. The most important areas where we have encountered difficulties include the following:

Approval of State Permit Programs. The law provides that EPA shall approve State permit programs which meet a number of requirements set out in the Act. Following approval, the States assume the primary responsibility for issuing discharge permits, with only limited Federal review. As many of you know, the law also authorized the approval of interim State permit programs which expired 5 months after enactment. The apparent assumption was that most State programs would be finally approved by that time. As things developed, however, many changes in statutes and regulations and significant changes in State programs were required in nearly every State. Thus, when the 18 interim authorizations which we granted expired in April 1973, not one State program had qualified for approval. To this date, only 5 State programs have been approved, and we now expect only 10-15 more will be approved by the end of June.

Yet, in spite of this slow rate of approvals, new statutory provisions providing stronger support for State programs have been enacted in some 25-30 States and are currently pending before State legislatures in another 5-10 States. Thus, although very real progress has been made at the State level, the primary responsibility for operating the permit program has remained with EPA far longer than we or anyone else would have expected a year ago. We are now, once again, urging Governors to initiate legislative action this session where it is still needed to obtain State program approval. This is an absolutely crucial link in the successful implementation of the national permit program.

Effluent Guidelines. As you know, the Act also required that, within one year after enactment, we publish effluent guidelines for various categories for dischargers. During the past 16 months, we have carried out an extremely energetic program to develop these guidelines. The initial set of guidelines cover "best practicable control technology currently available" (the 1977 standard), "best available technology economically achievable" (the 1983 standard), new source performance standards, and pretreatment standards for some 30 different industrial categories. A total of 121 separate standards are involved, each covering a variety of pollutants and many complex factors. At the present time, we have proposed the 4 different standards in each category for at least part of 21 different industrial categories. To date, none of the standards have been finally promulgated. In the meantime, we have continued to prepare industrial permits without waiting for the effluent guidelines to be finalized.

We have recognized all along that the development of the guidelines would be a long and difficult task, and that the 1977 compliance phase is not far away. Recently, adding more strain to our already hard-taxed schedule, we were ordered by a court to complete, by November 1974, the promulgation of all these guidelines and a great many others on which we have not yet commenced work.

Toxic Pollutants. One of the major disappointments in the implementation of the Act has been the technical difficulty we have encountered in developing a sound basis for regulating toxic pollutants. Since this represents one of the most critical needs in the water pollution program, the Act directs that we issue separate regulations to address this problem. Although we have issued an initial list of toxic pollutants and have proposed regulations to cover them, we continue to face inherent problems in attacking this need through the statutory mechanism provided. The statute specifies that the toxic pollutant standards must be met within one year after they are established. We have found it virtually impossible to devise intelligent standards which specify an appropriate degree of control over toxic pollutants irrespective of the sources of those pollutants and factors affecting the feasibility and timing of their abatement.

Planning. Another area in which achievement has fallen short of expectation is planning. Although most States have now developed an approved Section 303 planning process which satisfies our regulations, very few new river basin plans have been completed. It was our hope that a large number of plans would be completed by now, as part of the foundation for developing abatement requirements in permits. A special effort to collect data has been made and waste load allocations are being completed in most places where they are required. But, for the most part, we have been forced to abandon the hope of completing the plans themselves prior to the issuance of the permits. Another enormously important part of the statutory planning authority--section 208 area-wide waste treatment management plans--is just beginning to get off the ground, much to the frustration of many advocated, both in and outside EPA.

Construction Grants. Of all the problem areas we face in implementing the 1972 Act, the widest gap between expectation and achievement lies in the area of making federal grants for municipal waste treatment facilities. Our progress in approving construction grants has been held back by a variety of requirements. A year ago, approval of grant applications was delayed because we had not yet issued the basic regulations under the new statute. Shortly after those regulations were issued, the program became bogged down over the statutory requirement that no grants could be approved after March 1, 1973 unless they complied with cost recovery and user charge requirements, and we had not yet issued those regulations. After that problem was licked, we then became stuck by the need for each State, after July 1, 1973, to develop a new priority list for projects to be funded with the available grant funds. The upshot of all this is that of the $5 billion available as of January 1, 1973, less than $3 billion has been obligated. At the same time, of course, a national controversy has centered on the level of funding provided in the President's budget. Of the $18 billion authorized by law, the President has released one-half, or $9 billion. On an absolute scale and in a very real perspective, this level of Federal funding is not subject to wide-open attack. The $4 billion just released for the next fiscal year establishes a level of Federal funding five times higher than the breakthrough level of $800 million achieved by the Crusade for Clean Water in the budget for FY 1970. And it is almost 20 times higher than the funding of $214 million per year before that. On the other side of the issue, however, we now have a new Needs Survey showing construction projects which require some $60 billion. And the next Needs Survey is likely to increase even that mind-boggling figure.

In scanning this broad range of programs required by the 1972 Amendments, and in reciting the difficulties we have had in meeting the deadlines and objectives imposed by the Act, it is easy to lay blame for faulty implementation on those running the program. Being a participant, however, I leave that judgment to others who can be more objective than I. Insofar as the Environmental Protection Agency is concerned, it is doubtless true that we have made some mistakes. Yet I'll say this. In all my years as a private citizen, I never thought I would witness the intense dedication and sheer human effort I have observed in the past 16 months in trying to implement this massive program. I have watched EPA people working night after night, weekend after weekend, in a valiant struggle to meet these deadlines. I am convinced that if there have been weaknesses, it hasn't been for lack of a 100% effort on our part.

I believe there is a more fundamental problem which should be clearly stated and understood. The 1972 Act profoundly changed and expanded nearly every aspect of this country's water pollution control effort. An extremely short time frame was provided to make most of these changes. Moreover, in many cases, the changes were cumulative, in that certain steps were dependent on the accomplishment of preceding steps. Water quality standards had to be completely overhauled, with new standards established for all intrastate waters. Dozens of effluent standards also had to be established. Planning requirements were greatly expanded, with the obvious hope that in many instances these could be completed before specific point source abatement requirements would be finalized. Several major innovations were specified regarding the Federal waste treatment construction grants. Extensive new provisions for public participation were added. All of these required changes together heaped an incredible load on the shoulders of EPA and on many States which were not physically equipped to perform within the time provided. New state statutes and regulations also were required. This awesome task was all geared to achieving full compliance with effluent standards and water quality standards by 1977, less than 5 years after enactment.

Another fundamental problem with the 1972 Act is that it has some inherent inconsistencies. The most dramatic example of this is the so-called "funding gap" for municipal waste treatment facilities. EPA is faced with the dilemma of developing compliance schedules for these municipal sources where meeting the 1977/78 deadlines required by law is impossible, regardless of any level of funding that might reasonably be expected in 1975 and 1976 and irrespective of the courts' resolution of the impoundment issue. We cannot legally establish compliance schedules which extend beyond 1977/78, but we also cannot impose unrealistic or impossible deadlines. The most we can do in these cases is establish interim milestones which can be met. We also can stress the increased importance of local government action, which certainly should not always be dependent upon prior Federal action.

Underlying the 1972 Act was a major new commitment to water pollution that would require a great leap forward across the entire spectrum of water pollution abatement programs. The cold, sober appraisal I promised you at the outset leads me to conclude, at this stage of the game, that it isn't going to happen the way many of us hoped it would. Giant steps may be possible on the moon, but on Earth we generally have to proceed at a more measured pace.

National problems of the magnitude of our water pollution cannot be solved overnight. The vast machinery of government and industry cannot be completely transformed in a year or two or even three. One fundamental misconception underlying most provisions of the 1972 Act is a consistent failure to anticipate and allow for the workload implications of the new requirements, particularly the cumulative effect of these on the limited staff and funds of State pollution agencies.

In assessing our experience to date, it is important to analyze and understand the implications of the evident inability to achieve certain objectives contained in the Act. In some cases, the only consequence will be a moderate delay in obtaining the benefit. In other instances, we should recognize that the requirement may entail far more work than had been anticipated and that the benefits of it are perhaps not worth that extra work. Most importantly, we must recognize that in some instances the difficulty in achieving a specific requirement is holding back a much bigger program.

Since we cannot do everything at once, the clear need now is to focus in a practical, realistic, and common sense way on those steps which will be most productive in getting the job done, without a sense of panic or frustration in not being able to achieve unrealistic deadlines or commitments. As we try to draw from the experience of the past 16 months, it seems to me that several helpful pointers clearly stand out. I would emphasize the following areas where specific actions can be taken to improve our overall implementation efforts.

Simplification. First, and perhaps most importantly, vastly greater attention must be given to simplifying the procedures employed by government at all levels in administering water pollution control programs. Statutory and regulatory provisions alike must be interpreted and applied (and modified, where appropriate) with sensitivity to their workload and paper-flow implications.

Transition Period. Where major changes must be made in the requirements for program operations, reasonable time for adopting these changes must be allowed. On-going work and projects in advanced stages of development should not be interrupted pending full completion of the desired changes. This particularly applies to construction grants, where the "go back and do it over" syndrome must be avoided wherever possible.

Anticipation of Future Requirements. The 1972 Act wisely provides for a second phase pollution control activity to meet standards set for 1983. In many cases, planning requirements and other work will have greater significance with respect to this second phase. We should not impede the achievement of objectives that can reasonably be reached in 1977 by overzealous preparation and planning with regard to future abatement requirements.

Issuance of Permits. The national permit program is the major tool by which abatement programs will be specified and through which point source reductions will be made during the next several years. Federal and State personnel should give the highest priority to the development of abatement requirements and the issuance of permits.

Monitoring Program. Through the monitoring and reporting requirements developed during the past several years, and specifically those now being imposed in permits, tremendous masses of data are going to be generated in the next several years. One of our greatest management challenges will be to handle this data economically and effectively in order to support our enforcement efforts and conduct continuing analyses of receiving water conditions.

Enforcement. Stringent enforcement action must be taken as soon as violations of permit conditions appear. The kind of continuous "slippage" experienced under the 1965 Act must not be repeated. Attentive operation and maintenance of abatement facilities must be required.

Intergovernmental Cooperation. The success of the entire national water pollution program depends upon an exceptionally high degree of intergovernmental cooperation and coordination. EPA's primary responsibility should be to provide technical and financial assistance to the States. The States' primary responsibility should be to establish and operate programs which conform to national guidelines and accomplish clean water goals of each State. Local governments should make those decisions and perform those tasks which only they can. All levels of government must operate within a framework of guidelines and procedures designed to minimize confusion, duplication, and delay and maximize output. Output means getting pollution abatement equipment installed. This is the only measure of progress that is meaningful, and we must all pull together to accomplish it.

The Environmental Protection Agency recognizes that it has a leading responsibility to work toward these objectives. The first objective of simplification is perhaps the most important. In a number of cases, it appears that the ambitious enthusiasm of the statute was infectious and was carried forward in some of our regulations. We are now in the process of reviewing our regulatory requirements, looking for ways to make modifications which may make the requirements more flexible and workable. We are also looking for any modifications which should be made in the statutory provisions themselves, although our preference is to work through administrative changes where possible.

I hope it is understood that I am not challenging the efficacy or desirability of the goals of the 1972 Amendments. What I have focused on today are the transitory problems of getting to those goals. I have focused on them deliberately, because the record is increasingly clear that these are indeed serious problems. Putting together the nuts and bolts of a program that will work and actually making it operate involves something more than commitment, idealism, and deadlines. It requires a coldly practical and realistic attention to how much work is required, what is going to be done first, and what are the limits of the people and the resources available for the job. I believe that in our zeal we have in many instances overlooked some other basic facts of life. Some of the requirements are counter-productive, and some corrections are required.

There is one final message which also becomes clear as we look ahead. It is that the war against water pollution is by no means won, yet. We continue to have a long road to travel, and progress down this road will continue to demand intensive public support. This is most clearly true with regard to the cleanup of municipal sewage. Until recently, we thought we were facing an $18 billion job that we could tackle in 3 bites of $6 billion a year. But now we see ourselves facing a $60 billion job which we are pecking away at, at the rate of $3 or $4 billion a year. With regard to industrial pollution, the facts are not so dramatic. But there also, I am sure, we will need a continuous tightening of standards and increasing vigilance for many years into the future.

In short, the battle against water pollution is neither virtually won nor about to be over. We are making progress, and that is heartening. In the next several years visible progress should become evident around the country. But a real solution to infinitely complex pollution problems can be achieved only through a sustained national effort over a long period of time. Those responsible for management of the pollution programs in government must build them with an eye to continuing improvement in the years ahead.

Chapter 23

SUMMARY OF SYMPOSIUM PROCEEDINGS

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Blount set the stage by identifying some common ground for those concerned with water resources in the Southeast: the importance of water to agricultural productivity, the mutual concern of urban and rural populations for water, and what should be the inseparability, in our thinking, of the quantity and quality of water. He expressed the conviction that the growing realization of common interests in water makes the "emerging institution" that Ft. Valley State College is a fitting location for this symposium.

Ravan's keynote address focused on the control of water pollution, emphasizing difficulties of administering Federal water pollution control law and meeting the severe prescribed schedule. Meeting 10 deadlines every month is tremendous burden imposed by the 1972 Amendments (a "monumental achievement of environmentalists"). Slippages in schedules snowball. Water pollution control requires hard work by a dedicated staff (EPA has it), not "giant steps" appropriate to moonwalks. Sixteen months' experience with the amended law have taught some lessons:

- procedures for administering law, e.g., issuing permits, setting standards, must be simplified
- changing direction of water pollution control efforts requires time
- top priorities should be met first, then next priorities
- data being collected must be better managed and used
- law must be stringently enforced
- more, better intergovernment cooperation is necessary

The war on water pollution is not won: control of municipal sewage, thought to require $18 billion to solve in 3 years, now appears to need $60 billion over 10-15 years!

Knisel reviewed the brief history of hydrologic research especially that using experimental watersheds to develop hydrologic models. Federal erosion experiment stations date from the '20's, experimental watersheds from the '30's, watershed research centers from late '50's. Models being developed now are 3 types: stochastic, parametric, deterministic. USDA's southeast watershed research is using parametric approach. Water yield models are non-linear, based on seasonal storage functions, characteristic functions, and state functions. Uncertainties of hydrologic processes demand large amounts of data for analysis and inference, made possible by advent of digital computer. ("The hydrologist is not yet able to walk on water, but now he can find the rocks!")

Sewell reviewed some of the essential elements of hydrology and summarized the hydrologic features of the southeast region. He described the Southern Regional Project studying factors affecting water yields from small watersheds and shallow aquifers that was conducted in the '60's on numerous watersheds, mostly in Kentucky, Tennessee, Virginia. Using data from Tennessee watersheds, he demonstrated the variability in yield due to season and to physiographic region, and the not unusual but unexplained difference in yield between two adjacent, apparently similar, watersheds. He emphasized the importance of ground water, which remains generally only slightly utilized in the Southeast, and the problems associated with ground water recharge. He offered a number of problems deserving further research:

- improved watershed management
- effects of watershed modification
- predictive hydrologic techniques
- reduction of salt water encroachment on fresh-water aquifers
- improving natural and artificial recharge of ground water

Hill described current practices in the disposal of sewage and sludge on land, citing data from several instances in U.S. and Mexico. Irrigation with untreated sewage is forbidden in U.S., but not in all countries. Spray irrigation has a hazard of pathogen transport with droplets and drift. Disposal on land at Muskegon, Mich., at Penn State University, at several Florida locations, in California, Colorado and Mexico were illustrated and described. At Penn State on forest land, phosphorus removal is successful apparently indefinitely, but nitrogen removal is unsatisfactory after a few years' operation. On agronomic lands, nitrogen uptake by plants is limited only by supply. Build-up of metals in soil and in plants is apparently minor where sewage is applied, but may be significant with disposal of sludge on land. Sludge concentrations of heavy metals may range from a few ppm to 6,000 ppm (for zinc). Wastewater from plating shops, presumably a likely source of metals found in sludge, may not be the major source. Problems of sludge and sewage disposal on land are not insurmountable and should not disqualify the technique for further consideration in designing waste treatment systems.

Wilson described various uses of water in the Southeast, pointing out the unique reusable nature of water and its low cost and comparing it with petroleum as a natural resource of opposite characteristics. Water continue to be underpriced. Amounts used for airconditioning, irrigation, rural purposes, and public water supply average each about 1% of daily runoff in southeastern states. Industry uses 3 to 18% (46% in Florida). Withdrawals from groundwater constitute 4 to 37% of all withdrawals, indicating the groundwater in the Southeast is not tapped to the extent it is available. Water resources are now abundant for recreation. In year 2000, water demand will probably reach about 44% of runoff. The region generally has ample supplies.

Oertel reviewed the fundamental physical processes and social actions that lead to erosion of soil and subsequent deposition as sediment. Having summarized the early agricultural impetus to soil conservation efforts and their accomplishments, he described the critical need for such efforts to prevent damage from current rapid urban development. Four steps (firm public statements by public officials against erosion, aggressive leadership by soil and water conservation districts, effective ordinances, and abundant public information) to effective urban erosion control were explained using the Atlanta metropolitan area as a case study. Gwinnett County in 1972 passed the first Georgia ordinance requiring permits for nonagricultural land disturbance. Three other Georgia counties have followed, but a bill for a state law (8 states have such laws) died in the 1974 legislature. A popular SCS manual explains standards and specifications that are crucial for urban sediment control. Georgia Land Development Association has adopted a code of ethics incorporating much of the SCS manual. A continuing public information program is necessary for support of sensible erosion control ordinances. Researchers should develop better tools to predict erosion from urban watersheds.

Dornbusch addressed the classical agricultural control of erosion with many illustrations of conservation techniques. Using the Universal Soil Loss Equation as a model, he showed how modern practices could alter factors in the equation to reduce soil loss. A Soil and Water Conservation Plan developed with professional help by the soil conservationist is the basic tool for deciding on controls. Sound systems for managing crops (such as "no-till" systems) and water are essential. SCS is assisting in implementing plans so that the responsibilities of soil stewardship can be fulfilled.

Shirley discussed the role of forestry and forest management in watershed management: everyone is affected by the watershed, their habitat. A good watershed converts precipitation into clean useful water supply. Forests help make good watersheds by moderating temperature, dissipating rainfall energy, regulating runoff, performing photosynthesis and transpiration. Water quality is affected by kind of forest, for example, pines contribute less carbon than hardwoods, because of immobility of pine straw. Forests occupy 2/3 of nearly every Georgia watershed, producing the state's largest crop and increasing recreation and wildlife where well managed. Georgia watersheds are outstanding resource conservation developments and have achieved national recognition. Success is due to cooperation between all resource development agencies.

Whisler described five different types of wetlands in explaining that draining of wetlands for agricultural production often was detrimental to soil and surrounding ecosystems. Analysis shows such drainage is economical only when crops are subsidized. Before draining, each instance should be analyzed unless the area is isolated and within a single farm's boundary. Rice is a likely candidate crop for reclaimed wetlands. Wetlands offer water storage, recreation, wildlife habitats, and a means of recycling nutrients and wastewater. A recharge basin-drain system could be useful for the latter purpose. Use and modification of wetlands needs study by multidisciplinary teams, and the economics of their development needs re-evaluation.

Boyce explained the essential features of hardwood production in wetlands, characterizing areas by physiography and dominant species. Wetland forests contain 1/5 the total growing stock in the Southeast, with lower growth and removal and higher mortality than other forest types. Fifty-seven percent is soft-textured hardwoods. Half the forests are on stream margins, 1/4 in swamps. Recent analysis suggests a potential average growth of at least 70 ft^3 per acre per year on 10% of the area without culture. Growth of all wetland hardwoods can probably be considerably increased. Better community classifications are needed, as well as growth and yield functions. Research is needed to discover ways to regulate stand density and water, control species composition, regenerate stands, improve genotypes, and apply nutrients.

Smitherman summarized the extensive pioneering fish culture studies at Auburn University, noting U.S. efforts are only 6,000 years behind the Chinese, and using numerous excellent illustrations. Intensive culture systems using artificial fertilization and supplemental feeding have increased fish production in warm southeastern waters from about 100 lb. per acre (standing crop) in natural waters to 20,000 lb. per acre. Intensifying fish production alters water quality, increasing BOD, COD, phosphorus and nitrogen content. Water quality degradation can be prevented by mechanical aeration, polyculture with secondary fish species to consume waste feeds and detritus, aquatic plants to absorb nutrients and minimize excessive phytoplankton blooms, and recirculation and filtration of water to minimize BOD and COD. Research should be directed to improving water quality and maximizing fish production.

Caldwell discussed the effects of both treated and untreated wastewater on fish, game and wildlife. Fishes and benthic macroinvertebrates receive greatest direct impact. Species and number typically change, heavy pollution reducing number and species, but light pollution sometimes enhancing number and species. Blooms of nuisance organisms may result from nutrient discharges.

Silt usually has only subtle effects unless discharged in large amounts, which could destroy organism habitats. "Toxic and potentially lethal" pollutants may be accumulated in organisms rendering them unsuitable for human consumption. Heat can increase productivity; cold water from reservoirs can reduce number and diversity of species. Radioactive materials can affect reproduction, but total effect of accumulation in food chains is yet to be assessed. Water quality criteria, necessary to protect aquatic life from harmful effects of wastewaters, are prescribed by Georgia Department of Natural Resources. Research is needed on populations of aquatic organisms, on improved and standardized taxonomy methodology, and on ecological effects of specific pollutants.

Nicholson reviewed the problem of water pollution by agricultural pesticides and fertilizers, which can cause fish kills, eutrophication, or subtle responses, such as egg-shell thinness due to DDE (a degradation product of DDT). Pollution by agricultural chemicals has resulted from runoff, pesticide application to water, accidents, careless use or disposal, airborne materials, industrial manufacture or use, and municipal wastewaters. Probably 50 pesticides account for 90% of all pesticides sold. In 1971, production was over 1 billion pounds; 143 million acres of agricultural land were treated. Pesticide characteristics of toxicity, persistence and bioaccumulation created adverse effects that may be mitigated by dilution, degradation, and adsorption on sediments. Runoff is the single most common cause of fresh water pesticide contamination, which is generally less than 1 ug/l. Heavy rainfall shortly after pesticide application greatly increases loss in drainage. Aerial transport of drifting dusts or sprays or vapors frequently contaminates adjacent water. Pesticides adsorbed on soil may be airborne long distances, a likely mode of global transport of DDT. Accidental contamination is less frequent than in 40's and 50's when often bizarre accidents occurred. The relation of nutrients in runoff to fertilizer use is unclear. The balance between nutrient inputs and output is affected by cropping system, soil management, and climate. A better scientific basis is needed for legislation controlling fertilizer use. As a non-point source of water pollution, runoff containing agricultural chemicals is not amenable to engineering control, but must be regulated by preventive management, included in area waste management plans. Predicting pollution loads is being improved by research at EPA's Southeast Environmental Research Laboratory in cooperation with USDA's Southern Piedmont Conservation Research Center to develop simulation models. Other control research includes the development of alternative methods for pest control.

Pilney described the results of a study of the meat packing industry in which wastes produced by some 80 plants were quantified. Raw wastes have high organic content, depending upon plant housekeeping and waste use, but not hazardous pollutants. For slaughter and packing houses average 5-day BOD ranged from 6 to 16 lbs. per 1,000 lbs. of live weight killed. Off-site rendering plants produced an average of 1 lb. of 5-day BOD per 1,000 lbs. of raw material. In-place treatment systems gave up to 99.5% removal of BOD (by a combination of anaerobic and aerobic lagoons with aeration). Nitrogen and dissolved solids are the most troublesome constituents, although large losses of N by denitrification were observed; ammonia stripping is not a likely candidate treatment. The industry faces a difficult challenge to meet the zero discharge mandated by Congress.

Gerber stressed the importance of understanding the effects that agricultural and forest management have on the water system to help resolve future potential conflicts between urban and non-urban dwellers. Adverse effects of forestry and agricultural management on water quality are largely increased burdens of sediment and agricultural chemicals. Management practices including burning, clear cutting, logging, and draining, can have beneficial affects if conducted properly. Erosion control practices and intelligent use of fertilizers can minimize adverse effects. Proper clear-cutting and burning have been shown to increase water yield and quality. Logging and selective cutting can be conducted without loss of ground cover and subsequent increased erosion. Research is needed on all these aspects of agricultural and forestry management.

Phene reviewed the characteristics of the Atlantic coastal plain that affect cropping systems and agricultural water management, and outlined the requirements for irrigation in this region. He summarized the results of his studies of a porous tube irrigation system employing automatic control of soil moisture in the restricted root zone characteristic of the area. The new system was shown to be superior to sprinkler or furrow irrigation systems, giving greater corn yields and using less water than either. Materials and cost of construction were described. An advantage is the ease of applying water miscible pesticides in addition to nutrients.

Perkins reviewed the chemical and physical properties of soils that affect drainage, emphasizing their dynamic equilibrium. Soil drainage is both a cause and an effect. Morphology, both macro and micro (such as soil texture) and the hydrologic sequence of drainage influence water movement. Different water regimes influence soil classification. Soil color is indicative of moisture and oxidation state and deposition of metals. Well drained (aerobic) or poorly drained (anaerobic) systems profoundly affect chemistry and biology of soil, and its heat capacity. Degree of drainage influences color, oxidation state, pH, availability of nutrients, soil microbiology, production of toxins, and soil temperature.

Skinner described current practice for both surface and subsurface drainage systems to solve problems of excess water on soil surfaces or subsurface root zones. The type of surface drainage system (parallel, random, cross slope or diversion) must fit the farming system, have adequate discharge capacity, be consistent with local construction and maintenance, and conduct water without harmful erosion or silt deposition. Land smoothing and grading are valuable adjuncts to ditching. Subsurface drainage, either relief drainage to lower a high water table or interception drainage to divert water from a problem area, may employ open ditches or buried drains. Buried drains have been constructed primarily of corregated polyethelene tubing since 1967; over two million feet were installed in Georgia in 1973. It is light, inexpensive, and easy to use, although high temperatures reduce its strength and low temperatures reduce its flexibility. Plastic tubing requires a specially shaped trench bottom and proper blinding and back-filling.

Chesness described drip or "trickle" irrigation, compared it with other conventional irrigation systems, and showed the design of a system for a peach orchard. An emitter, or trickler, dissipates water under low pressure at several points around a plant to provide a continuous supply of soil moisture sufficient to meet transpiration needs. Developed shortly after WWII in the United Kingdom and later in Israel, drip irrigation conserves water, energy, and nutrients, with the potential for increased yields, accelerated growth, and reduced weed and insect control costs additionally. Its main disadvantages are sensitivity to clogging, poor soil moisture distribution, and build up of soil salinity. Using a representative design example, annual operating costs of a drip system were shown to be one-fourth Diesel- or electrical-operated sprinkle systems. Fuel consumption was one-eighth and annual water use was one-fifth that of comparable sprinkle systems. More research is needed to determine crop response to reduced water quantities, reduced root zone wetting, fertilizer applications and pesticide applications.

Sanders and Mahotiere reviewed the significance of water in vegetable culture. Vegetable quality is especially sensitive to water content; crop yields are severely reduced by water deficits. Irrigation decisions are greatly assisted by scheduling methods, such as Martin's evaporation accounting system or Hiler's stress day index system. Drip irrigation, impermeable moisture barriers in sandy soils, and evaporative cooling irrigation are especially useful procedures. Water management for vegetable crops or fruits is not yet sufficiently understood.

Kiker summarized the historical and recent law regulating water rights. Earlier concepts of water use as a right vested in all people are being modified to meet the needs of an increasingly complex society. The Florida Water Resource Act of 1972, as an example, changes many rights enunciated under old riparian doctrine, injecting strong public interest considerations, such as the hydrologic interrelationship of all waters. Requirements for permits for all consumptive uses, waste disposal, and physical modifications of water resource systems have major effects on water rights. Enhancement or curtailment of public or private water rights will depend upon the ability of water management districts to operate a permit system technically and equitably.

The symposium covered comprehensively agriculture's involvement with water: conservation and management of supplies, hazards to water quality and some means of controlling them, and even urban erosion control where rural erosion control practices are finding application. Those concerned with other non-agricultural aspects of water resources should gain valuable insight from these symposium papers.

GLOSSARY

Common and Scientific Names of Plants

Common Name	Scientific Name
Alfalfa	Medicago sativa L.
Algae	Cyanophyta
Asparagus	Asparagus officinalis
Beakrushes	Rhynchospora
Beets	Chenopodiaceae
Bermuda grass	Cynodon dactylon
Cabbage	Brassica oleracea var. capitata
Carrot	Dancus carota var. sativa
Cauliflower	Brassica oleracca var. botnytis
Celery	Apium graveolens
Chufa	Cyperus erculentus
Cocklebur	Xanthium Pennsylvancium
Coontail	Cerato phyllem demersum
Corn	Zea mays L.
Cotton	Gossipium hirsutum L.
Cucumber	Cucumis sativus
Dotted smartweed	Polygonum
Grapes	Vitaceae
Green beans	Phaseolus vulgaris
Green peas	Pisum sativum
Italiam millet	Fall panicum
Lettuce	Lactuca sativa
Muskgrasses	
Muskmelon	Cucumis melo
Naiads	Najas marina
Oats	Avena sativa L.
Onions	Allium cepa
Peanuts	Arachis hypogaea
Pepper	Capsicum annuum
Pitcher plants	Sarracenia
Pole beans	Phascolms vulgaris
Pondweeds	Potamogeton sp.
Potato	Salanum tuberosum L.
Prunes	Prunus domestica
Raspberry	Rubus Sp.
Reedcanary grass	Phalaris arundinacea

Rice	Oryza sativa
Rose	Rosa bracteata
Smartweeds	Polygonum hydropoper
Snap bean	Phasolus vulgaris
Sorghum	Sorghum vulgare
Soybeans	Glycine max L.
Spatterdocks	Nuphar advena
Sphagnum moss	Lycopodium
Strawberry	Fragaria
Sugarcane	Saccharium officinarium
Summer squash	Cucurbita pepo
Sweetcorn	Zea mays saccharata
Sweet potato	Ipomoea batatas
Tealgrass	
Waterlillies	Nymphaea
Watermelon	Citrullus vulgaris
Watermilfoils	Myriophyllum
Wildcelery	Vallisneria spiralis
Wild millet	Echinochloa crusgalli

Common and Scientific Names of Forest Trees

Common Name	Scientific Name
Alder	Alnus sp.
Almond	Amydalus communis
American elm	Ulmus americana
American sycamore	Platanus occidentalis
Ash	Fraxinus
Atlantic white	Chamaecyparis thyoides
Bald cypress	Taxodium distichum
Bitternut hickory	Hicoria cordiformis
Blueberries	Gaylussacia
Buttonbush	Cephalanthus occidentialis
Cherry	Prunus incisa, P.
Cherrybark oak	Quercus rubra var.
Cottonwood	Aspen
Cranberries	Vaccinium macrocapon
Crypress	Cupressus
Cyrilla	Racemiflora
Dogwood	Cornus
Eastern cottonwood	Populus deltoides
Elm	Ulmus fulva

Fern	Cyathea arborescens
Florida elm	Ulmus Floridana
Gordonia	Gordonia lasianthus
Green ash	Franxinus
Heath shrubs	Erica
Laurel oak	Quercus laurifolia
Loblolly pine	Pinus taeda L.
Longleaf pine	Pinus palustris, Syn.
Mockernut hickory	Hicoria alba
Ogeechee tupelo	Nyssa ogeche
Olives	Oleaceae
Overcup oak	Quercus lyrata
Persea	P. americana
Pond cypress	Taxodium ascendens
Pond pine	Pinus rigida var. serotina
Redroot cyperus	Cyperaceae
Red maple	Acer rubrum
Red pines	Pinus resinosa
Shagbark hickory	Hicoria ovata
Shumard oak	Quercus, shumardii
Silver maple	Acer sarrharinum
Slash pine	Pinus elliottii
Slippery elm	Ulmus fulva
Southern magnolia	Magnolia grandiflora
Spruce pine	Tsuga caroliniana
Swamp black gum	Nyssa sylvatica
Swamp chestnut oak	Quercus prinus
Swamp-privet	Forestieva acuminata
Swamp tupelo	Biflora
Sweetbay	Magnolia virginiana
Sweetgum	Liguidambar styraciflua
Tupelo gum	Nyssa aquatica
Tupelos	Nyssa
Virginia chainfern	Woodwardia
Walnuts	Juglans
Water hickory	Carya aquatica
Water-hyacinth	Eichornia crassipes
Water oak	Quercus nizra

Water tupelo	Nyssa aquatica
White ash	Fraxinus americana
Willow oak	Quercus phellos
Willows	Salix sp.
Yellow poplar	Liriodendron tulipifero

Common and Scientific Names of Fishes

Common Name	Scientific Name
Bluegill	Lepomis macrochirus
Buffalofish	Ictiobus
Channel catfish	Tilapia aurea
Clapper rails	Rallus longirostrus wagnei
Crayfish	Cambarus latimanus
Largemouth bass	Micropterus salmoides
Rainbow trout	Salmo gairdneri
Threadfin shad	Dorosoma petenense
White catfish	Ictalurus catus L.

ASA QUICK CONVERSIONS*

Rate or Yield

kg/ha	lb/A	bu/A		kg/ha	lb/A	bu/A	
		56#	60#			56#	60#
1	0.9			900	800		
2	1.8			1000	890	16	15
3	2.7			2000	1800	32	30
4	3.6				ton/A**		
5	4.5			3000	1¼	48	45
10	9			4000	1 3/4	64	59
20	18			5000	2 ¼	80	74
30	27			6000	2 3/4	96	89
40	36			7000	3	112	105
50	45			8000	3½	125	120
60	54	1		9000	4	145	135
70	62		1	10000	4 ½	160	150
80	71			11000	5	175	165
90	80			12000	5¼	190	180
100	89			13000	5 3/4	205	195
200	180		3	14000	6¼	225	210
300	270	5		15000	6 3/4	240	225
400	360		6	16000	7	255	240
500	450	8		17000	7½	270	255
600	540		9	18000	8	285	270
700	620	11		19000	8½	305	285
800	710	13	12	20000	9	320	295

*American Society of Agronomy, Madison, Wisconsin
**English short tons (2000 lbs)

ASA QUICK CONVERSIONS (cont'd)

Rate or Yield

TEMPERATURE

°C	°F
100	212
90	194
80	176
70	158
60	140
50	122
40	104
35	95
30	86
25	77
20	68
15	59
10	50
5	41
0	32
-5	23
-10	14
-15	5
-20	-4
-25	-13
-30	-22
-40	-40

LENGTH

cm	inch
2½	1
5	2
10	4
20	8
30	12
40	16
50	20
60	24
70	28
80	32
90	36
100	39
200	79
	feet
300	10
400	13
500	16
1,000	33

VOLUME

liters	quarts
1	1.1
2	2.1
3	3.2
4	4.2
5	5.3
6	6.3
7	7.4
8	8.5
9	9.5

MISCELLANEOUS

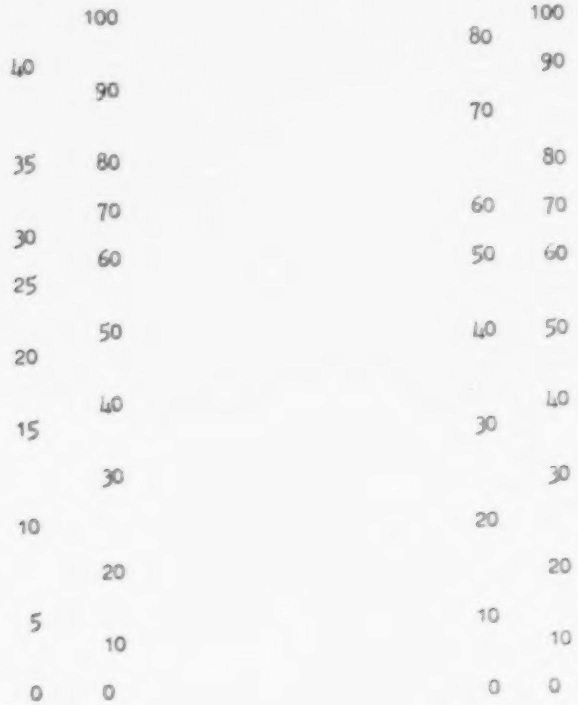
1 gram = 0.035 ounce
1 kilogram = 2.2 lbs
1 quintal = 100 kg = 221 lbs
1 metric ton = 1000 kg
= 2,205 lbs
1 hectare = 2.5 acres
1 meter = 39.4 inches
1 kilometer = 0.6 mile

FERTILIZER CONVERSION SCALES*

P H O S P H O R U S		P O T A S S I U M	
Phosphorus	phosphorus pentoxide	Potassium	Potassium oxide
P	P_2O_5	K	K_2O

Pounds or Percent

Pounds or Percent



$P \times 2.29 = P_2O_5$
$P_2O_5 \times 0.44 = P$

K x 1.20
$K_2O \times 0.83$

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*Iowa State University of Science and Technology COOPERATIVE EXTENSION SERVICE, Ames, Iowa.

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